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Contents

Unit 1 Diversity of Living Things . . 2

Focus on STSE: A First or Last Chance to See? 3
Are You Ready? 4

Chapter 1: Understanding Biodiversity 6
1.1 Biodiversity—An Introduction 8
1.2 The Nature of Classification 14
1.3 Phylogeny and Modern Taxonomy 21
1.4 Kingdoms and Domains 26
1.5 Biology Journal: Birds—In a Class of their Own 30
Investigation 1.2.1: Using and Constructing a Dichotomous Key 32
Investigation 1.4.1: Sampling the Diversity of Life 34
Chapter 1 Summary 36
Chapter 1 Self-Quiz 37
Chapter 1 Review 38

Chapter 2: Prokaryotes, Viruses, and Protists 44
2.1 The Prokaryotes: Eubacteria and Archaea 46
2.2 Viruses, Viroids, and Prions 54
2.3 The Protists 60
Investigation 2.1.1: Observing Bacteria 68
Investigation 2.3.1: Observing Protists 69
Chapter 2 Summary 70
Chapter 2 Self-Quiz 71
Chapter 2 Review 72

Chapter 3: The Fungi, Plants, and Animals . 78
3.1 The Fungi 80
3.2 The Plants 86
3.3 The Animals 96
3.4 Explore an Issue in Biodiversity: Fisheries in Peril 108
Investigation 3.1.1: Growing and Observing Fungi . . 110
Investigation 3.3.1: Representing the Six Kingdoms of Life 111
Chapter 3 Summary 112
Chapter 3 Self-Quiz 113
Chapter 3 Review 114
Unit 1 Task: Diversity at Risk 120
Unit 1 Self-Quiz 122
Unit 1 Review 124

Unit 2 Genetic Processes 132

Focus on STSE: Shaping Our Past and Our Future 133
Are You Ready? 134

Chapter 4: Heredity and Reproduction . . . 136
4.1 The Nature of Heredity 138
4.2 Asexual Reproduction: Copies and Clones 142
4.3 Sexual Reproduction: Adding Variety 152
4.4 Abnormal Meiosis and/or Fertilization 161
4.5 Cytoplasmic Inheritance 167
Investigation 4.3.1: Observing Meiosis 171
Investigation 4.4.1: Interpreting Karyotypes 172
Chapter 4 Summary 174
Chapter 4 Self-Quiz 175
Chapter 4 Review 176

Chapter 5: Mendelian Genetics—Patterns of Inheritance 182
5.1 Mendelian Inheritance 184
5.2 Variations in Heredity 194
5.3 Pedigrees—Tracking Inheritance 197
5.4 Biology Journal: The Gene Hunters 202
5.5 Genetic Disorders 204
5.6 Explore an Issue in Genetic Screening: Who Decides? Who Wants to Know? 208
5.7 Multi-trait Inheritance 210
Investigation 5.2.1: Gummy Bear Genetics 215
Investigation 5.3.1: My Genetic Profile 216
Chapter 5 Summary 218
Chapter 5 Self-Quiz 219
Chapter 5 Review 220

Chapter 6: Genetics beyond Mendel. 226
6.1 DNA and the Code of Life 228
6.2 Mutations. 234
6.3 Genomes 240
6.4 Manipulating the Genome 245
6.5 Gene Therapy 249
6.6 **Explore Applications in Genetics:** Genetic Technology—The New Medicine 252
Investigation 6.3.1: Comparing DNA Fingerprints . . 254
Chapter 6 Summary 256
Chapter 6 Self-Quiz 257
Chapter 6 Review 258

Unit 2 Task: Assessing a Genetic Concern. . . . 264
Unit 2 Self-Quiz 266
Unit 2 Review. 268

Unit 3 Evolution 276

Focus on STSE: In Pursuit of Poisons 277
Are You Ready? 278

Chapter 7: The Theory of Evolution. 280
7.1 Biological Change over Time 282
7.2 The Evolution of an Idea 288
7.3 Biology Journal: Voyage of the HMS *Beagle*. . . . 294
7.4 The Evidence for Evolution. 296
7.5 On the Origin of Species. 304
7.6 The Modern Theory of Evolution 308
Investigation 7.5.1: Modelling Natural Selection 314
Investigation 7.6.1: A Walk through Time. 315
Chapter 7 Summary 316
Chapter 7 Self-Quiz 317
Chapter 7 Review 318

Chapter 8: The Origin of Species 324
8.1 Natural Selection 326
8.2 Speciation 336
8.3 Patterns of Evolution 341
8.4 **Explore an Issue in Evolution:** Avoiding Extinctions. 346
8.5 Macroevolution. 348
8.6 Biology Journal: *Tiktaalik*—Triumph of a Theory 356
8.7 Human Evolution 358
Investigation 8.1.1: Bird Monogamy and Sexual Dimorphism 366
Investigation 8.5.1: Looking for SINEs of Evolution. 367
Investigation 8.7.1: Human and Chimpanzee Chromosome Comparison 368
Chapter 8 Summary 370
Chapter 8 Self-Quiz 371
Chapter 8 Review 372

Unit 3 Task: Evolution for Everyone 378
Unit 3 Self-Quiz 380
Unit 3 Review. 382

Unit 4 Animals: Structure and Function 390

Focus on STSE: Whole Body Scans 391
Are You Ready? 392

Chapter 9: Nutrition and the Digestive System. 394
9.1 Why We Need to Eat 396
9.2 What and How Much We Need to Eat 400
9.3 Introducing Digestion 406
9.4 Digestion in the Mouth and Stomach 408
9.5 Digestion in the Small and Large Intestines. . . . 412
9.6 Nausea, Vomiting, and Diarrhea 421
9.7 Biology Journal: Scientific Detective Work 424
Investigation 9.5.1: Factors Affecting the Digestion of Starch. 426
Chapter 9 Summary 428
Chapter 9 Self-Quiz 429
Chapter 9 Review 430

Chapter 10: The Respiratory System 436
10.1 The Need for a Respiratory System 438
10.2 Respiratory Structures and Processes 440
10.3 Transport and Diffusion of Gases 447
10.4 Interference with Gas Exchange. 452
10.5 Lung Transplants and Other Technologies. 459
10.6 **Explore an Issue in Healthcare:** Is Healthcare a Right, a Privilege, or a Responsibility? 463
Investigation 10.2.1: Determining Lung Volume and Oxygen Consumption 465
Investigation 10.2.2: The Relationship between Long-Term Exercise and Vital Capacity 467
Chapter 10 Summary 468
Chapter 10 Self-Quiz. 469
Chapter 10 Review. 470

Chapter 11: The Circulatory System 476
11.1 The Need for a Circulatory System 478
11.2 Blood: A Fluid Tissue 482
11.3 Blood Vessels. 487
11.4 The Cardiac Cycle and Circulation 495
11.5 Coronary Artery Disease. 501
11.6 Imaging: Looking through the Body. 504
11.7 **Explore Applications of Technology in Diabetes Management:** Technology for Insulin Delivery 508
Investigation 11.1.1: Fetal Pig Dissection. 510
Investigation 11.3.1: The Effect of Exercise on Heart Rate and Blood Pressure 513
Investigation 11.4.1: Analyzing and Interpreting ECGs 514
Chapter 11 Summary 516
Chapter 11 Self-Quiz. 517
Chapter 11 Review. 518

Unit 4 Task: Health and Fitness Profile and Plan 524
Unit 4 Self-Quiz 526
Unit 4 Review. 528

Unit 5 Plants: Anatomy, Growth, and Function 536
Focus on STSE: Waking Up to Coffee. 537
Are You Ready? 538

Chapter 12: The Importance of Plants . . . 540
12.1 The Characteristics of Plants 542
12.2 Leaves. 546
12.3 Stems 552
12.4 Roots. 558
12.5 Transport in Vascular Plants. 564
12.6 Biology Journal: Biomimicry 571
12.7 **Explore Applications in Urban Greening:** Improving City Life with Trees 573
Investigation 12.2.1: Leaf Structure in Vascular Plants 575
Investigation 12.3.1: Comparing Monocot and Eudicot Stem Cross-Sections 576
Investigation 12.4.1: Comparing Monocot and Eudicot Root Cross-Sections 577
Chapter 12 Summary 578
Chapter 12 Self-Quiz. 579
Chapter 12 Review. 580

Chapter 13: Succession, Reproduction, and Sustainability 586
13.1 Succession 588
13.2 Asexual Reproduction in Seed Plants 592
13.3 Sexual Reproduction in Seed Plants 595
13.4 **Explore an Issue in Energy Alternatives:** Biofuels. 603
13.5 Plant Growth and Development 605
13.6 Control of Plant Growth and Development. . . . 613
Investigation 13.2.1: Methods of Asexual Reproduction 619
Investigation 13.5.1: Temperature, Light, and Seed Germination. 620
Investigation 13.5.2: Factors Affecting Plant Growth and Differentiation 621

Chapter 13 Summary 622
Chapter 13 Self-Quiz 623
Chapter 13 Review 624

Unit 5 Task: Plants That Changed the World 630
Unit 5 Self-Quiz 632
Unit 5 Review 634

Appendix A **Skills Handbook** 643

Appendix B **Reference** 668

Appendix C **Answers** 674

Glossary 678
Index 689
Credits 702

UNIT 1

Diversity of Living Things

OVERALL EXPECTATIONS

- analyze the effects of various human activities on the diversity of living things
- investigate the principles of scientific classification using appropriate sampling and classification techniques
- demonstrate an understanding of the diversity of living things, in terms of both the principles of taxonomy and phylogeny

BIG IDEAS

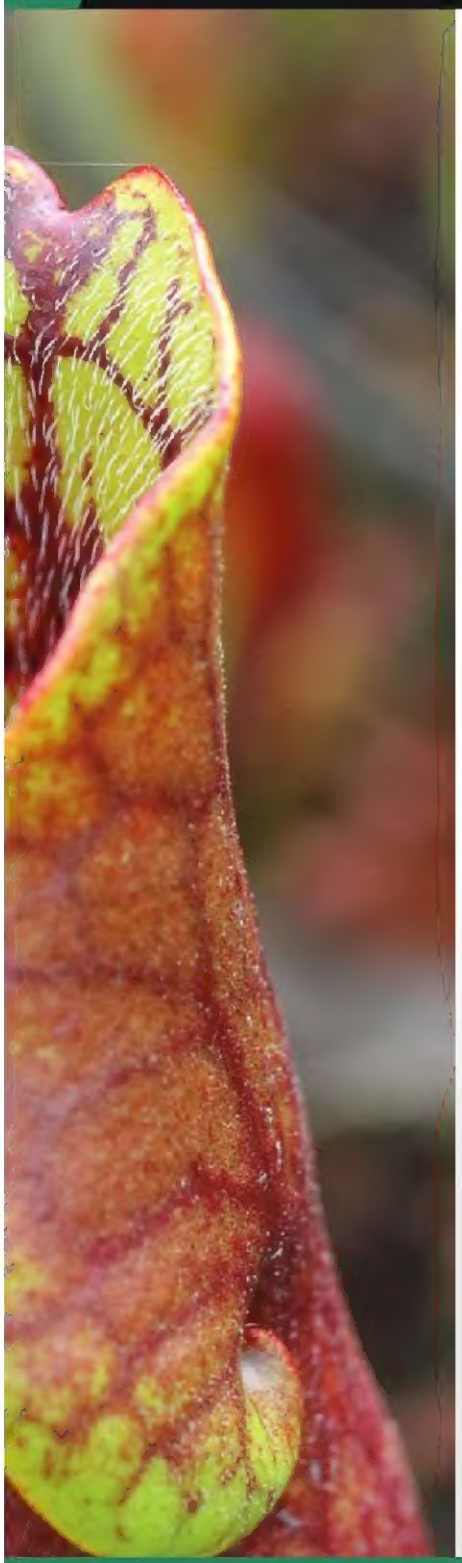
- All living things can be classified according to their anatomical and physiological characteristics.
- Human activities affect the diversity of living things in ecosystems.

UNIT TASK PREVIEW

In the Unit Task you will select a group of organisms and then examine the role the group plays in supporting ecosystems. You will investigate specific threats to the group's diversity by examining how human actions influence it in both negative and positive ways.

The Unit Task is described in detail on page 120. As you work through the unit look for Unit Task Bookmarks to see how information in the section relates to the Unit Task.

FOCUS ON **STSE**



A FIRST OR LAST CHANCE TO SEE?

The biosphere contains an astounding diversity of living things. Living things inhabit virtually every square metre of Earth's surface, from the deepest ocean trenches to the highest mountain tops. Life comes in a truly astonishing array of shapes and sizes, both familiar and bizarre. You may recognize and admire bald eagles, humpback whales, and polar bears, but know little about—and even fear—vampire bats, tarantulas, and giant squid.

Biologists discover new types of living things daily, but they have catalogued only a fraction of the millions of different kinds of living things thought to inhabit Earth. Biologists also continue to discover important interconnections among organisms. For example, most plants rely on soil fungi to get nutrients from the soil, and most animals depend on microscopic organisms living within their bodies to help them digest food.

You are fortunate because you will have the opportunity in your life to admire, study, and benefit from the millions of kinds of organisms with which you share this planet. If you are lucky, you may see moose while hiking or paddling through Ontario's beautiful old growth forests, or examine the several types of small carnivorous plants that live in Ontario bogs. You may travel to an ocean to go whale watching or scuba over a coral reef, or perhaps visit a tropical rainforest!

Unfortunately, opportunities like this are limited by past human actions and may be limited even more in the future. Climate change, habitat destruction, pollution, and the introduction of invasive organisms are posing a serious threat to the diversity of life on a global scale. For the many living things that are endangered, the situation is grave. The years ahead may be our last chance to see them before they become extinct.

The situation is far from hopeless, however. Actions and decisions we make can help sustain healthy ecosystems and conserve the diversity of life on Earth. In this Unit, and throughout this book, you will learn about the connections between science, technology, society, and the environment (STSE). Making wise choices today while keeping these connections in mind can ensure that future generations have a chance to see, admire, and experience this amazing diversity of life.

Questions

1. Some kinds of organisms are far more dramatic than others. People often marvel at their first sight of an elephant or whale, a beautiful flower, or a towering tree.
   (a) In a small group, brainstorm a list of 10 or more of the most interesting kinds of organisms. Provide reasons for your selections.
   (b) Which of these organisms have you seen in real life? Which would you like to see?

2. Humans are very dependent on other organisms for survival. Other organisms supply us with foods, clothing, medicines, and building materials.
   (a) Did your list of organisms in question 1 include organisms that benefit you?
   (b) In your group, make a second list of 10 or more organisms that you think are most important to humans. Explain your reasoning.

3. Although people are most familiar with plants and animals, the living world also contains many kinds of fungi, protists, and other microscopic organisms. Do you think these organisms are as important as plants and animals? Why or why not?

4. Many scientists are concerned about threats to Earth's biodiversity. Do you share this concern? What responsibility do you think we have to protect biodiversity?

UNIT 1 ARE YOU READY?

CONCEPTS

- understand scientific terminology related to cells, organisms, and ecosystems
- compare and contrast different kinds of cells
- recognize the postulates of the cell theory
- understand that all living things are interdependent
- recognize that human actions influence other species and the sustainability of ecosystems

SKILLS

- make biological drawings
- properly use and care for a microscope
- prepare dry and wet mount slides
- make and record careful observations
- communicate ideas, plans, procedures, results, and conclusions using appropriate scientific terminology and formats
- analyze and interpret qualitative and quantitative data

Concepts Review

1. The following key terms are associated with the ways in which scientists gather information and conduct investigations. Explain the meaning of each term: K/U T/I
   (a) hypothesis
   (b) independent variable
   (c) dependent variable
   (d) controlled experiment
2. Decide if each statement is true or false. If it is true, copy it directly into your notebook. If it is false, rewrite it to make it true. K/U
   (a) All living things are made up of many cells.
   (b) Living things grow, reproduce, and repair themselves.
   (c) Most living things require energy to function.
   (d) Animals respond to changes in their environment, but plants do not.
   (e) All organisms perform photosynthesis, but only plants perform cellular respiration.
3. Match each term with correct definition. K/U

(a) mutualism	(i) a situation in which two organisms live in close contact and at least one benefits
(b) symbiosis	(ii) a situation in which one organism lives in or on another organism and feeds on that organism
(c) parasitism	(iii) a situation in which two organisms live in close contact and both benefit
(d) commensalism	(iv) a situation in which two organisms live in close contact; one benefits and the other is not affected

4. Describe the relationships among an embryo, tissues, and the process of cell differentiation. K/U
5. Many biology news stories refer to advances in genetics. How are the terms "genetic" and "genetic information" related to chromosomes, DNA, and inherited information? K/U T/I
6. State the function of each of the following: K/U
   (a) chromosomes
   (b) mitochondria
   (c) chloroplasts
   (d) flagella
   (e) DNA
   (f) ribosomes
   (g) nuclei
7. Compare and contrast the following terms: K/U
   (a) cell wall and cell membrane
   (b) unicellular and multicellular
   (c) mitosis and the cell cycle
8. State the function of each of the following: K/U
   (a) muscle tissue
   (b) nervous tissue
   (c) vascular tissue
   (d) epithelium
9. Biologists classify organisms into large groups called "Kingdoms." Copy the table and place each of the following organisms under the proper kingdom heading. Note that only the five most well known kingdoms are included. K/U

tuna	mushroom	fern	amoeba
salmonella	ant	bread mould	yeast
slug	*E. coli*	moss	

Bacteria	Protists	Fungi	Plants	Animals

10. We are most familiar with plants and animals, but they are just two groups of organisms on Earth. List two or three characteristic features of the following groups of living things: K/U
    (a) protists
    (b) fungi
    (c) bacteria

11. (a) What does the term "micro-organism" mean?
    (b) Give one or two examples of micro-organisms.
    (c) What invention was necessary for the discovery of these organisms?
    (d) How did this invention alter our understanding of all organisms? K/U
12. Brainstorm a list of different kinds of organisms that might live in a particular habitat, such as a forest, field, or pond. Then draw a hypothetical food web that shows how they are interconnected. T/I C
13. How does a food web illustrate the interdependence of one kind of organism with another? Use an example from your food web in question 12 to explain what would happen to the ecosystem if one kind of living thing were removed. T/I A
14. Give one or two examples of ways in which living things influence and are dependent upon
    (a) the carbon cycle
    (b) the water cycle
    (c) the nitrogen cycle K/U A
15. Humans interact with other kinds of living things in many ways. Some of these interactions are harmful to ecosystems. Match the term on the left with the description of the interaction on the right. K/U A

(a) invasive species	(i) Humans are producing large quantities of greenhouse gases that trap thermal energy.
(b) monoculture	(ii) Habitat loss and pollution can lead to the loss of a species from a particular region.
(c) climate change	(iii) Humans often introduce organisms into new environments with unforeseen consequences.
(d) extirpation	(iv) Humans often grow crops in large fields containing a single kind of plant.

16. Humans can also act to ensure that ecosystems remain sustainable. K/U T/I A
    (a) What does "sustainable" mean?
    (b) Give an example of an action you could take to improve the sustainability of ecosystems.
    (c) How is the sustainability of an ecosystem influenced by the diversity of living things in the ecosystem?
17. You, like all humans, depend on other organisms for food. But food is only one of the many benefits to humans of other organisms. Brainstorm and list the many ways that you benefit from other organisms in your daily life. T/I C A

Skills Review

18. Examine the cells in **Figure 1**. K/U T/I A
    (a) Identify each cell as a plant, animal, bacteria, or protist. Give reasons for your choices.
    (b) What evidence suggests that some of these organisms have the ability to move?
    (c) What evidence suggests that one of these organisms has the ability to produce its own food?

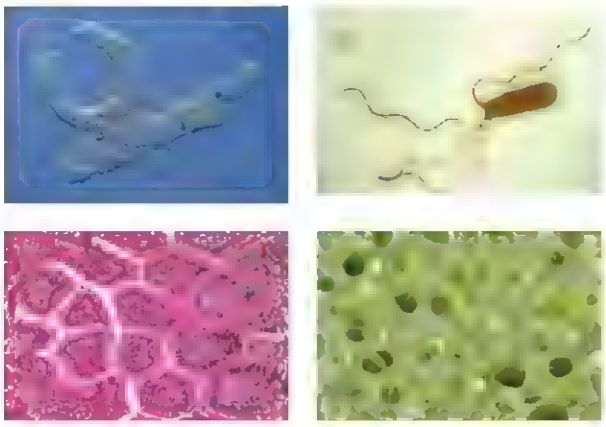


Figure 1

19. List the characteristics of a good biological drawing. K/U
20. Make a biological drawing of one of the cells in Figure 1. K/U C
21. Describe how you would make a wet mount of a sample of banana cells. C
22. Describe the step-by-step procedure you would use to observe cells under high power. T/I C
23. Suggest several safety precautions that you think should be taken when studying live organisms. A
24. When you use the Internet for research, you often find countless different sources of information.
    (a) What criteria do you use to determine if the information is accurate and reliable?
    (b) What steps do you take that allow you to use and present this information effectively without plagiarizing? T/I C

CAREER PATHWAYS PREVIEW

Throughout this unit you will see Career Links in the margins. These links mention careers that are relevant to the diversity of living things. On the Chapter Summary page at the end of each chapter you will find a Career Pathways feature that shows you the educational requirements of the careers. There are also some career-related questions for you to research.

CHAPTER 1

Understanding Biodiversity

KEY CONCEPTS

After completing this chapter you will be able to

- describe the nature of biological diversity and the biological species concept
- outline some of the primary human-caused threats to Earth's biodiversity
- explain the principles of taxonomy and phylogeny and the concepts of taxonomic rank
- describe and compare traditional and modern biological classification systems
- outline some of the key features used to classify all living organisms into six kingdoms
- construct and apply dichotomous keys for the purpose of identifying species
- use appropriate sampling methods to collect specimens from an ecosystem and classify them using scientific criteria

What Connects Life on Earth?

Life can be found almost everywhere. Organisms live at the bottom of the ocean abyss, deep underground, on icy mountaintops, and in boiling hot springs. Even our own bodies are home to countless microscopic organisms—we are *their* habitat!

Emperor penguins show many of the most dramatic and fascinating qualities of living things, such as the ability to live and flourish in extreme environments. Emperor penguins begin life by hatching from an egg during sunless days on a sheet of ice in the most inhospitable continent on Earth—Antarctica. Surviving temperatures of –60 °C, they are cared for and protected by their parents until they are able to march for tens of kilometres to the water's edge. As they plunge into the icy water, they transform from awkward waddlers into majestic, high-performance swimming machines, faster and more agile than almost any fish!

As unique and marvellous as penguins are, they are just one of the millions of remarkable organisms on Earth. Our planet is also home to elephants with noses that drag on the ground, albatrosses that can stay airborne for more than a year at a time, and deadly poisonous stonefish hiding in coral reefs. Some eastern white cedar trees in Ontario are over 1000 years old!

The diversity of life is truly extraordinary. It is also immeasurably valuable. All organisms depend on other organisms for survival. Organisms provide us with oxygen, clean air and water, food, medicines, and building materials.

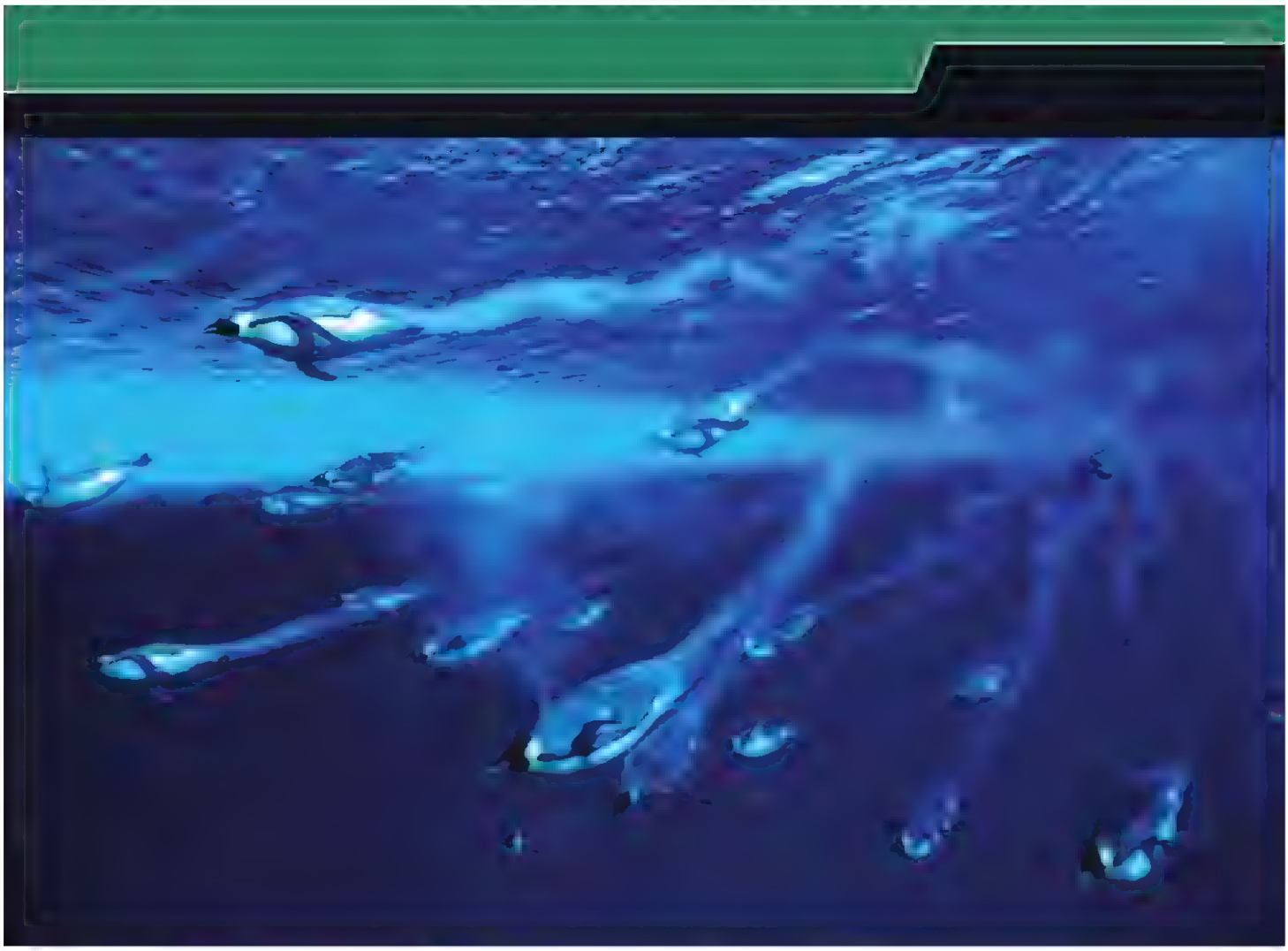
Some organisms are extremely numerous, and others are quite rare. In Ontario, mosquito and black fly populations naturally number in the billions. In contrast, populations of the eastern mountain lion and prickly pear cactus have probably always been relatively low. But throughout the world, native plant and animal populations are declining due to habitat loss, pollution, over-harvesting, and competition with invasive species. Many species are threatened with extinction.

In this chapter you will examine the grandeur of life, beginning with an exploration of the diversity of life and our dependence on it. You will learn how organisms are identified and classified, and gain insights into why scientists are so concerned about the threats to the diversity of life.

STARTING POINTS

Answer the following questions using your current knowledge. You will have a chance to revisit these questions later, applying concepts and skills from the chapter.

1. How many different kinds of living things do you think there are on Earth? How might this diversity be important or valuable?
2. How do you think organisms can be distinguished from one another?
3. What do you think are the benefits of naming and classifying (or grouping) living things? How might this be accomplished?



Mini Investigation

Identify the Extremes of Life

Skills: Questioning, Predicting, Communicating

SKILLS HANDBOOK A2.1

A good way to begin a study of the diversity of life on Earth is to consider the great variety of organisms that you are already familiar with. In this activity you will brainstorm examples of living things that fall into given categories and suggest some categories of your own.

1. Working in small groups, brainstorm examples of organisms on Earth that you think best fit the following categories:
   - largest living animal
   - most beautiful organism
   - smallest plant
   - most valuable food
   - most unusual animal
   - most powerful predator
   - most colourful animal
   - most dangerous organism
   - most valuable fungus
   - fastest flyer
   - fastest swimmer
   - three more categories of your own choosing

   You may list more than one kind of organism for each category, but you must identify which of these you think is the "best" choice.
2. Record your choices in a table or other suitable format.
3. Have a class discussion in which groups argue in favour of their selections. Be prepared to change your mind if others have a better case for their choice.

A. Which categories are based on opinion, and which are based on an objective characteristic? KT/I

B. Did everyone interpret the categories in the same way? Did "valuable" or "dangerous" have the same meaning for everyone? KT/I

C. Were there any choices that almost everyone agreed with? Why do you think that was the case? KT/I

1.1 Biodiversity—An Introduction

biodiversity the number and variety of species and ecosystems on Earth

Life on Earth is extraordinarily diverse. The variety and number of life forms on Earth is called biological diversity, or **biodiversity**. By 2010, the International Year of Biodiversity, over 1.7 million kinds of living things had been identified and described by scientists. This number continues to grow as new organisms are discovered daily. Among them are strange creatures from the depths of Earth's oceans (**Figure 1**), brightly coloured rainforest birds, and some peculiar organisms, such as tree kangaroos! Biologists believe that Earth may be home to as many as 15 million different kinds of living things.

Figure 1 Biologists continue to discover new organisms, such as the deep ocean Dumbo octopus.

In order to assess the diversity of life, scientists must observe and accurately describe each kind of living thing. Where do scientists begin? The first step is to choose a fundamental unit. In the case of living things, this unit is the *species*. However, defining and identifying this unit is not always easy.

What Is a Species?

species all organisms capable of breeding freely with each other under natural conditions

Most biologists define a **species** as a group whose members are able to freely breed among themselves under natural conditions. This definition is also referred to as the biological species concept. It is important to note that members of different species *usually* do not breed with one another. For example, under natural conditions lions breed only with lions, robins breed only with robins, and so on.

hybridization the cross-breeding of two different species

morphology the physical appearance and characteristics of an organism; also the science of the study of these physical characteristics

In many cases, the difference between species is obvious. For example, you would never mistake an elephant for a hippopotamus, or an ostrich for a turkey. Unfortunately, the traditional definition of species does not always hold true to all living things. Plants, for example, offer many exceptions. Two plants that appear to be distinct species may occasionally undergo **hybridization** under natural conditions, forming a cross between the two species. Although hybridization in nature does occur, it is relatively uncommon. Other plants, some fungi, and many microscopic organisms (micro-organisms) only reproduce asexually. For these organisms, the traditional species definition does not apply. When this is the case, species are defined based on a set of physical characteristics, or **morphology**. For example, dandelions (which reproduce asexually) are defined by their shared features rather than as members of a population of breeding individuals.

Figure 2 Humans exhibit individual variability but are all members of the same species.

Individual Variability

Atoms of an element or molecules of a compound are identical, but a species is composed of individuals with different traits. The individuals of any given species may show subtle differences (**Figure 2**). However, these individuals still belong to the same species and are members of the same breeding population.

As you will learn in the Genetic Processes unit, biologically inherited information (called genetic information) is a primary source of individual variability. The study of the diversity of living things focuses on distinctions among species, but individual variability is vital to both individuals and entire populations.

Variation over Time and Space

Species also change over time and space. They can evolve, or change, over many generations, and they can change across continents (**Figure 3**).

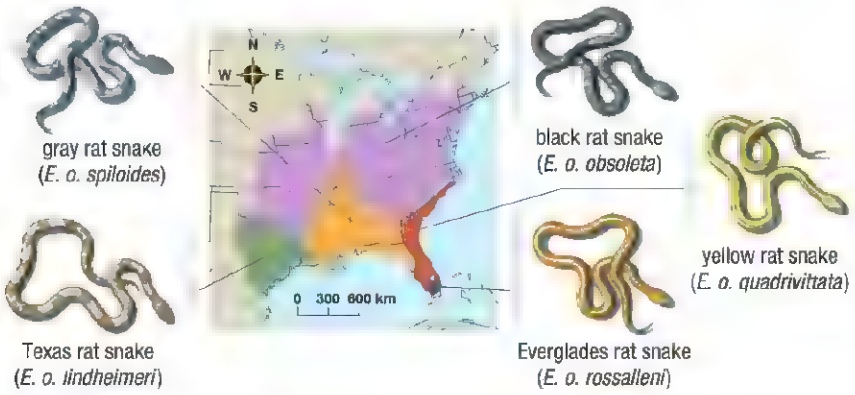


Figure 3 Five subspecies of rat snakes. These snakes are all considered members of the same species. They exhibit differences in colour and the presence or absence of stripes, depending on their geographic location.

The physical and behavioural changes that occur in entire populations of a species over time are referred to as **evolutionary changes**. Populations may separate and, over time, may form entirely new species. You will examine the factors influencing evolutionary changes in much greater detail in Unit 3.

evolutionary change a change that occurs in an entire population; usually occurs over a long period of time

Evolutionary changes usually occur over long periods of time and over long distances. However, in a particular location and at a particular time, species generally change little. For example, raccoons from Ontario may vary significantly from those in South America, but are much less variable within the Greater Toronto Area.

Biodiversity

Species come in all shapes and sizes—from microscopic organisms to massive marine mammals (**Figure 4**). Different species vary in their behaviours, habitats, ecological niches, and abundance. They also vary in their genetic makeup, referred to as **genetic diversity**. Individuals of a sexually reproducing species inherit unique combinations of genetic information from their parents. This produces genetic diversity. Examples of human genetic diversity are differences in hair, skin, and eye colour, as well as in facial features and adult height.

genetic diversity the genetic variability among organisms; usually referring to individuals of the same species

How do biologists make sense of this enormous array of diversity? What role does the diversity of life play in the functioning of ecosystems? Just how important is biodiversity? To begin to answer these questions, we will examine diversity in ecosystems.

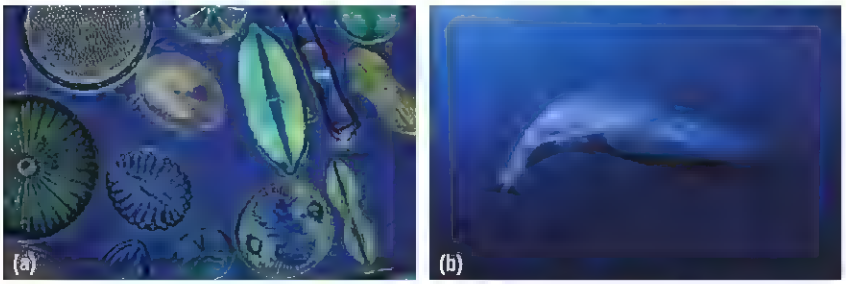


Figure 4 (a) This light microscope image shows several diatoms. Diatoms are a distinctive group of single-celled algae, characterized by their intricately patterned, glass-like cell walls. Diatoms form an important part of the plankton at the base of the marine and freshwater food chains. There are over 10 000 species of diatoms. (b) The blue whale is thought to be the largest animal that has ever lived. Its tongue alone weighs more than 2500 kg!

Diversity in Ecosystems

heterotroph an organism that obtains energy-rich nutrients by consuming living or dead organisms

autotroph an organism that uses sources of energy to produce nutrients from water, gases, and/or minerals

Ecosystems are made up of many different species and their physical environment. All these species depend on other species in some way for their own survival. For example, organisms that cannot make their own food, called **heterotrophs**, feed on other living or dead organisms. Even organisms that are able to make their own food, called **autotrophs**, are dependent on other organisms. Plants are examples of autotrophs. They depend on micro-organisms to recycle nitrogen, carbon, and other nutrients as part of biogeochemical cycles, and many depend on animals for pollination.

CAREER **LINK**

Ecologists
Ecologists are scientists who study ecosystems. To learn more about becoming an ecologist,

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Diversity of Interactions

The interdependence of one species on another goes far beyond simple food chains and biogeochemical cycles. For example, the important activities and processes of one species may depend entirely on another species for success (**Table 1**, next page).

Species support each other, and they also contribute to the stability and productivity of their ecosystems. Plant communities with a greater number of species are better able to withstand and recover from diseases, climate extremes, and pest infestations. They are also more biologically productive than plant communities with fewer species. For example, researchers have found that grasslands with mixed species are more than twice as productive as grasslands planted with a single species.

Of course, the larger the population of a species, the more interactions it will have. Diversity is therefore also influenced by the total number of individuals present in an ecosystem. An ecosystem with many large populations is considered more diverse than an ecosystem made up of smaller populations. For example, an ecosystem with 10 species—each with 500 individuals—is considered more biologically diverse than an ecosystem with 10 species—each with only 50 individuals.

species diversity a measure of diversity that takes into account the quantity of each species present, as well as the variety of different species present

The term **species diversity** describes both the variety of species in an ecosystem and the number of individuals within each of those species. The greatest species diversity exists in ecosystems with many different species that each have large populations.

Diversity of Habitats

structural diversity the range of physical shapes and sizes within a habitat or ecosystem

The range of physical sizes, shapes, and distribution of the individuals, as well as habitats and communities in an ecosystem, are together referred to as **structural diversity**. Structural diversity is critical for biodiversity because it creates microhabitats with a variety of abiotic conditions (**Figure 5**).

An ecosystem with greater structural diversity can support a greater diversity of species—it has greater biodiversity. This is why the biodiversity of a healthy rainforest is much greater than that of an even-aged tree plantation, in which all trees are the same height (**Figure 6(a)**). Aquatic ecosystems also exhibit a great range of structural diversity. Flat, smooth ocean bottoms offer little shelter for organisms, while irregular bottoms with rocks, reefs, logs, or even sunken ships enhance the range of microhabitats available for organisms (**Figure 6(b)**).

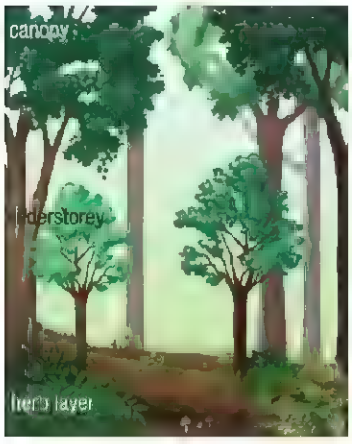


Figure 5 This mature forest has abundant structural diversity.

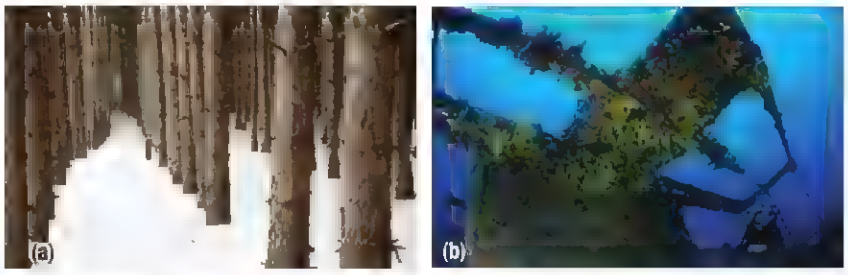
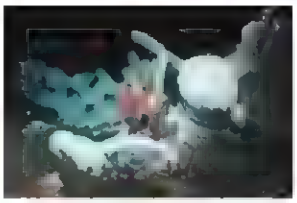
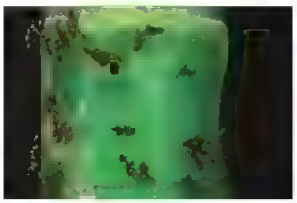
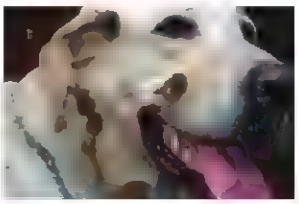
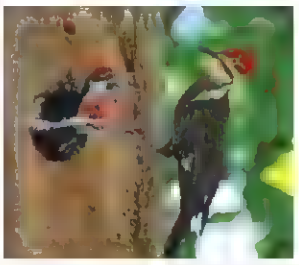
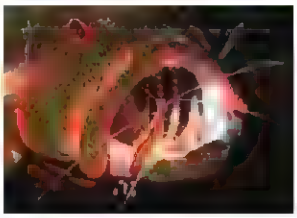


Figure 6 (a) Even-aged tree plantations, often established after clear-cutting, exhibit almost no structural diversity. (b) Artificial reefs made from sunken ships or aircraft increase the structural diversity of the ocean bottom.

All this variety challenges biologists to create methods of distinguishing and identifying species that resemble one another, and to name and categorize species in a systematic and consistent way.

Table 1 Species Interactions

Interaction	Examples (Organisms shown in the photos are bolded.)	
Food supply: Complex relationships exist between species and their food.	• **Boneworms feed exclusively on the bones of dead whales** that sink to the bottom of the ocean. • Photosynthetic micro-organisms live inside the bodies of giant clams and coral animals on reefs. They perform photosynthesis and supply the clams and corals with a steady supply of food.	
Protection: Many species depend on others for shelter and protection.	• Herm t crabs use the shells of dead snails for a protective home. • **Certain species of ants live within the trunks of Cecropia trees.** The trees provide shelter for the ants. The ants protect the tree by biting and stinging any herb vores that try to eat from it.	
Transportation: Many species move from place to place with the help of another species.	• Some flower mites climb onto the bills of hummingbirds moving from flower to flower feeding on nectar. • **Many seeds have hooks that allow them to stick to passing animals.** They can then be carried long distances before they fall off and begin grow ng.	
Reproduction: Many species depend on other species for their own successful reproduction.	• Trilliums produce seeds with fleshy tissues that attract ants. The seeds are then gathered and d spersed by the ants. If the ants do not feed on this outer seed tissue, the seeds cannot germinate • Many bird species build their nests in the abandoned **tree cavities made by woodpeckers for their own nests.**	
Hygiene: Some species help maintain the health of another species.	• Coral reefs have "cleaning stations" where **large fish come to have external parasites removed by small fish and shrimp.** • The bacteria that naturally live on our own skin help protect us from other bacterial and fungal .nfections.	
Digestion: Species living within digestive tracts are essential for the digestion of food.	• Termites consume wood but are almost entirely incapable of digesting it themselves. Instead, a variety of bacteria and other micro-organisms living within the termites' guts do the digestion for them. • **Bacteria living in the large intestines of humans** produce vitamins that are absorbed into the circulatory system.	

Biodiversity at Risk

There is no doubt that all species depend on one another. Maintaining and enhancing biodiversity is essential for the health and sustainability of ecosystems. Although more than 10 000 new species are discovered each year, there is grave concern among the world's leading biologists that the diversity of life is declining rapidly.

The loss of biodiversity affects humans in many ways. Loss of biodiversity

- threatens our food supply when entire species and plant varieties are lost
- eliminates sources of natural medicines and potential new medicines
- has a significant economic impact on tourism and forestry when accompanied by habitat destruction
- has the potential to cause serious disruptions in biogeochemical cycles, including normal carbon uptake by natural ecosystems

Species extinction is a natural process. Some biologists estimate that a new species will, on average, become extinct after approximately one million years. Of course, extinction rates for species are variable and may be relatively low at times and relatively high at others.

The history of life on Earth includes a number of mass extinction events—relatively short time spans during which a large proportion of Earth's species became extinct. The most famous mass extinction event occurred approximately 65 million years ago and resulted in the extinction of most dinosaurs.

Past mass extinction events have been linked to large-scale disruptions in Earth's climate, caused by factors such as comet and meteor impacts, and volcanic activity. A change in climate may make conditions too hot or cold, or too wet or dry for species adapted to the original climatic conditions. In contrast, today's high rate of species extinction is tied directly to human activity. Human actions are resulting in a rapid loss of natural habitats due to agriculture, forestry, urban expansion, the introduction of invasive species, over-harvesting of wild populations, and serious air and water pollution. The production of greenhouse gases is also resulting in human-caused climate change. These human actions, among others, are now operating on a global scale and are increasing the rate of species extinction.

Many Canadian species, especially those living in the Arctic, are already feeling the impact of climate change. Caribou depend on lichens and small ground plants as a source of food. While a milder climate does not harm caribou directly, it is causing changes in Arctic vegetation. Smaller plants are being displaced by larger shrubs, reducing the available food supply for the caribou (**Figure 7**).

WEB LINK

To learn more about extinct species and species currently at risk,

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CAREER LINK

Conservation Biologists

Conservation biologists study the threats to species and their habitats. To learn more about this career,

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Figure 7 This healthy caribou is shedding the "velvet" from its set of large antlers. Unfortunately, caribou and other Arctic species are already starting to feel the impacts of climate change.

While it is not possible to know the precise rate of species extinction, Edward O. Wilson, one of the world's most eminent biologists and an authority on biodiversity, conservatively estimates losses at a rate of 27 000 species per year. He believes we are witnessing a new mass extinction event—one that we are causing.

1.1 Summary

- The biological species concept defines *species* as a population of individuals that are able to freely breed under natural conditions.
- Biologists have identified and described more than 1.7 million species.
- All species depend on other species in a variety of ways for their own survival.
- Species evolve over time and space.
- Biodiversity refers to the variety of species in an ecosystem but also includes structural diversity within ecosystems and individual variability within species.
- New species are still being discovered, but biodiversity is under threat from many human activities.

1.1 Questions

1. Suggest three examples of species that clearly fit the definition of a species based on the biological species concept. Explain your choices. K/U
2. Explain why some species must be defined based on their morphology rather than on reproductive behaviour. K/U
3. Different forms of a species—like the subspecies of eastern rat snakes—are associated with different geographic locations. Suggest a possible explanation for this. T/I
4. Distinguish between an autotroph and a heterotroph. Include examples. K/U
5. Species are involved in a diverse range of interactions. Provide a specific example of each of the following types of interactions. K/U A
   (a) One species removes parasites from another species.
   (b) One species needs help from another species in order to reproduce.
   (c) One species defends another species against attack.
   (d) One species transports the offspring of another species.
   (e) One species provides a place for another species to live.
6. Describe four ways in which one species may be dependent on another for its survival. Include an example for each. K/U A
7. What is meant by the following terms? K/U
   (a) biodiversity
   (b) structural diversity
   (c) genetic variability
8. Analyze some ways in which a loss of biodiversity might affect the following industries: T/I A
   (a) agriculture and forestry
   (b) tourism
   (c) healthcare
9. Conduct research and describe one or two methods scientists and organizations use to increase the biodiversity of damaged ecosystems. T/I
10. How could the structural diversity of the following environments be increased? K/U
    (a) a landowner who wants to increase the structural diversity of an even-aged tree plantation
    (b) a government agency that wants to increase the structural diversity of a new marine park
11. Consider the numbers of species known to exist on Earth, including the numbers that are being discovered and the numbers thought to be going extinct. What do these numbers suggest about biodiversity on Earth? T/I
12. At the current rate of extinction, approximately how many years will it take for one million species to become extinct? T/I
13. E.O. Wilson estimates that the current extinction rate may be as much as 10 000 times as great as it would be without humans. What are some of the primary human activities responsible for this increased rate of extinction? K/U
14. Using the Internet and other resources, research how climate change is affecting biodiversity in the Arctic. K/U T/I
    (a) What changes in the climate have been observed to date?
    (b) How is climate change affecting the structural diversity of Arctic ecosystems?
    (c) Why are changes in Arctic ecosystems significant for the rest of the world?
15. Consider an ecosystem that you are familiar with (for example, a park near your home or school.) K/U T/I A
    (a) Why is biodiversity important to that ecosystem?
    (b) Brainstorm how loss of biodiversity would affect your chosen ecosystem.

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1.2 The Nature of Classification

Figure 1 Sorting and classification systems are used often in everyday life, such as in the supermarket.

biological classification the systematic grouping of organisms into biological categories based on physical and evolutionary relationships

Classification systems are extremely useful. Everyday classification is simply the grouping together or sorting of items into various categories based on some set of criteria.

In everyday life we use, and are surrounded by, many classification systems. In an online music store, for example, digital recordings may be classified according to the many styles of music: classical, jazz, rock, country, hip hop, rap, and so on. Within a category, items can be further divided into subcategories. Rock music might be further divided into indie rock, rock and roll, progressive rock, heavy metal, and so on.

Classification systems serve many purposes (**Figure 1**). They are very convenient, making it easy to find what you are looking for when shopping, looking for files on your computer, using the Yellow Pages of a phone book, or performing searches on the Internet. Classification systems are also a source of information and a tool for communication—how an item is classified tells you something about the item. You might expect a menu item listed as a dessert to be sweet. Similarly, you know that food listed as seafood came from the ocean. Defined categories show the relationships among items.

Scientists also use classification systems. By using the same classification systems, scientists can share ideas more easily. In chemistry, elements are carefully arranged in the periodic table into families. Chemists classify substances as metals and nonmetals, and as acids and bases.

In biology, organisms can be classified in many ways. The systematic grouping of organisms into categories on the basis of defined criteria is called **biological classification**. Familiar and ecologically important categories include producers, herbivores, carnivores, and scavengers (**Figure 2**). For example, when a biologist describes a massasauga rattlesnake as a carnivore, other biologists immediately know what that means.

Figure 2 Scientists often classify organisms according to their role in ecosystems: (a) kelp is a producer, (b) a sea urchin is a herbivore, (c) a massasauga rattlesnake is a predator, and (d) a vulture is a scavenger.

Classifications are useful in our everyday lives and for scientists. But how are they established? How do you choose a classification system for a particular use? How can you efficiently and accurately group items into chosen categories?

Mini Investigation

Creating a Classification System

Skills: Questioning, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1

Several steps are involved in creating a classification system. First, you must clearly identify each species. You must then select categories that will help you sort the species, based on the end use of your classification system. In this activity you will work in a small group to create a classification system for a variety of living things.

1. Have each member of your group brainstorm a list of 10 species of plants and animals that have been domesticated by humans.
2. As a group, decide on a set of categories into which you will sort or classify your species. Think of an underlying rationale for your categories. For example, you might want to distinguish between species used in agriculture and species found in the home.
3. Work with your group members to sort your species into your chosen categories.

A. Did you have difficulty deciding on your categories? If so, explain the challenge. T/I

B. Did you have difficulty deciding which category a particular species should be placed in? Did some species seem to fit into more than one category? T/I

C. Exchange your list of species and categories from Steps 1 and 2 with another group. Now redo Step 3 using their 10 species and their chosen categories. When you are done, compare your results. Did everyone agree on how to sort species in a set of the chosen categories? T/I

D. Do you think you could fit any domesticated species into your categories? Explain why or why not. T/I C

E. Do you think there might be one "best" classification system for species? Explain your reasoning. T/I C

Taxonomy—Developing a Classification System

The best criteria to use for classifying organisms depend on the purpose of the classification system. For example, a tourist in Costa Rica might be very interested in bird watching. It is essential that a mushroom picker know which varieties of mushrooms are poisonous (**Figure 3**). It might be useful for all members of the public to recognize invasive species.

Although these specialized classification systems are essential for particular purposes, biologists need a more general classification system that they can use to organize all living and fossil species. **Taxonomy** is the science of identifying and classifying all organisms. With millions of species living on Earth, and countless extinct species, taxonomy is a challenging science. Taxonomy is also referred to as the "Science of Systematics."

Figure 3 The "death angel" is one of many species of poisonous mushrooms.

taxonomy the science of classifying all organisms; taxonomists classify both living and fossil species

The Need for Identification

Before you can classify objects or species, you must be able to identify them. One way biologists identify organisms is by observed characteristics—morphology, behaviour, and even geographic location.

You might think that it is easy to recognize species—after all, no one would mistake a dog for a cat, a giraffe for an elephant, or a maple tree for a pine tree. Surely a specialist can tell even the most similar-looking species apart? Or can they? For some categories, there are thousands of species! **Table 1** shows some species numbers.

To make matters even more challenging, individuals of the same species are variable—males differ from females, and individuals change in appearance as they grow (**Figure 4(a)** and **(b)**). Different populations of the same species can also vary, exhibiting striking differences from one location to another (**Figure 4(c)** and **(d)**).

Table 1 Species Variety

Category	No. of species
Ontario mosquitoes	> 50
fish of Lake Malawi, Africa	> 1000
wasps	> 100 000
seed-producing plants	> 260 000

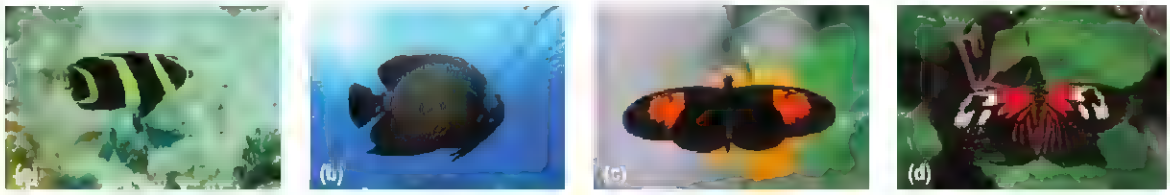


Figure 4 The juvenile (a) and adult grey (b) angelfish are the same species but do not appear similar. These passion-vine butterflies, (c) and (d), belong to the same species, but inhabit different geographic ranges. They have evolved different wing coloration.

Another challenge is that species also evolve over time. Evolutionary change is usually slow and gradual, happening over thousands or millions of years. It must be considered by taxonomists studying the fossil record. It must also be considered by taxonomists studying species that are known to undergo more rapid evolutionary change. For example, evolutionary changes in many micro-organisms can happen over months or even days.

Today, biologists have powerful new tools to use in taxonomy. Every species and most individuals of sexually reproducing species have a unique and characteristic set of genetic instructions in their DNA. Unfortunately, it is not always possible, and not often practical, to try to identify organisms in the field by sampling and examining their DNA. However, with advances in technology, this may soon change.

Early Biological Classification Systems

Many animals that are of direct interest to humans are relatively easy to identify. The same is not true of plants. Many plants look quite similar, and when not in flower can be quite difficult to tell apart. Many plants are also toxic. It is therefore not surprising that the skills of the shaman and other Aboriginal healers depended on their ability to identify and classify plants. The earliest written record of plant names dates back to Ancient Greece, more than two thousand years ago. Today, scientists who specialize in the study of plants are called **botanists**. Botanists study over a quarter of a million species of living organisms.

botanist a scientist specializing in the study of plants; also called a plant biologist

Early names and classification systems were extremely variable. Species were given different names in every language, and there were no agreed-upon criteria for the basis of a common classification system. Biologists, and botanists in particular, wanted to create a system based on a clear set of rules and a rationale that could be applied to all living things.

The first challenge was to develop a scientific name for each species. The everyday or "common" names for species are not always helpful. For example, Europeans and North Americans use the common name "robin" for two different species of birds.

Carl Linnaeus

Swedish naturalist Carl Linnaeus (1707–1778) is considered the "father" of taxonomy. He introduced a consistent way of grouping species according to their morphological (or physical) similarities. He also established a naming system that is still used today.

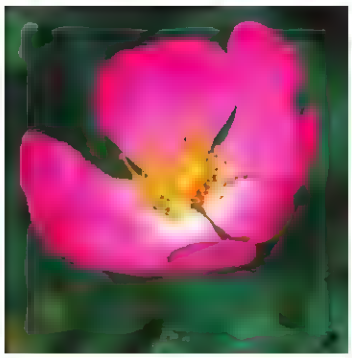


Figure 5 Linnaeus gave the briar rose the scientific name *Rosa canina*.

Linnaeus considered species to be distinct types of living things that could be grouped into categories called **genera** (singular: genus) according to shared characteristics. This was not a new idea, but previous systems of grouping were often quite arbitrary—for example, placing all farm animals, or all water animals, in the same genus. Linnaeus based his groupings on similarities among the organisms themselves, not on an external relationship such as where they lived.

genus a taxonomic level consisting of a group of similar species

Before Linnaeus, naming practices varied widely. It was common for species to be given one or more long descriptive names. For example, the briar rose (**Figure 5**) was named both *Rosa sylvestris inodora seu canina* (the odourless woodland dog rose) and *Rosa sylvestris alba cum rubore, folio glabro* (the pinkish white woodland rose with smooth leaves).

Linnaeus felt that each species should have a unique name. While he made use of long descriptive names at first, Linnaeus decided for convenience to also assign to each species a binomial (two-word) short-form name. His short name for the briar rose was *Rosa canina*. Using Linnaeus's binomial naming system, the first name is the genus name (*Rosa*) and the second name is the specific name (*canina*). Taken together, the two words form the species name—*Rosa canina*. This **binomial nomenclature** system is now the formal system used to name species.

binomial nomenclature the formal system of naming species whereby each species is assigned a *genus* name followed by a *specific* name; the two words taken together form the species name

Although the classification criteria Linnaeus chose were often flawed, his simple and convenient binomial naming system was a major improvement and quickly became standard. Species in the same genera could be expected to have similar characteristics. As a result, knowing the names of two species, such as *Ursus americanus* (black bear) and *Ursus maritimus* (polar bear), told you that that these species likely share many characteristics. On the other hand, a species of a different genus, *Phascolarctos cinereus* (koala), likely does not share as many features with the *Ursus* genera. In this case the koala "bear" is a marsupial with a dramatically different anatomy and is more closely related to kangaroos than to true bears.

The Great Chain of Being

Many early classification systems were based on the philosophical assumption that each type of organism held a fixed position, or rank, on a scale from lowest to highest. Humans were positioned at the top, mammals and birds were above frogs and fish, and all animals were above plants. This hierarchy, referred to as the Great Chain of Being, or the *scala naturae*, resulted in very complex plants being positioned below even the simplest animals—an orchid below a flatworm or hydra, for example (**Figure 6**). The philosophy also entrenched the notion that species were fixed, unchanging over time. Many scientists were very reluctant to abandon this belief, even as strong evidence mounted against it.

Later in life, Linnaeus was among the first prominent biologists to doubt this fixed nature of species. He theorized that new species might arise through hybridization and that plants might change as they became acclimatized to new environments.

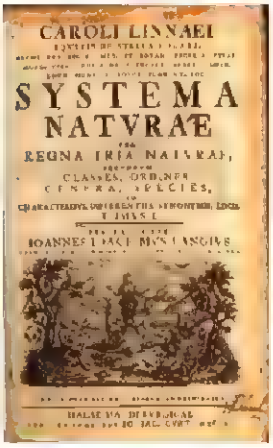


Figure 6 In the first edition of his book *Systema Naturae* (1735), Linnaeus grouped species and genera into orders, classes, and kingdoms.

Traditional Taxonomic Levels

Linnaeus further grouped species into taxonomic ranks, or levels, based on shared characteristics. Each level is called a **taxon** (plural: taxa). Linnaeus's original system consisted of five taxa and was later modified to include seven major levels: similar species were grouped into genera, similar genera into families, similar families into orders, orders into classes, classes into phyla, and phyla into the highest taxonomic level—**kingdom**. Linnaeus placed all organisms into just two kingdoms: plants and animals. At that time all algae and fungi were considered plants. **Table 2** illustrates how four different organisms can be classified using this system.

taxon a category used to classify organisms

kingdom the highest taxonomic level of the traditional Linnaean system of classification

Table 2 Traditional Taxonomic Ranks of Classification

Taxon	Human	Walrus	Bald eagle	Honey bee
kingdom	Animalia	Animalia	Animalia	Animalia
phylum	Chordata	Chordata	Chordata	Arthropoda
class	Mammalia	Mammalia	Aves	Insecta
order	Primates	Carnivora	Accipitriformes	Hymenoptera
family	Hominidae	Odobenidae	Accipitridae	Apidae
genus	*Homo*	*Odobenus*	*Haliaeetus*	*Apis*
species	*Homo sapiens*	*Odobenus rosmarus*	*Haliaeetus leucocephalus*	*Apis mellifera*

In the Linnaean system, each taxonomic rank consists of species that have similar features. For example, all species in the phylum Chordata have a backbone or a primitive backbone. Similarly, all members of class Mammalia are warm-blooded and feed milk to their young.

In an effort to further refine the classification of more than one million species, taxonomists have created many intermediate taxonomic levels, such as superorders and subfamilies.

LEARNING TIP

Naming Species

The first word of a binomial species name is always capitalized. The second word is always lowercase. Both words are printed in italics. The names of other taxonomic levels are normally capitalized. Binomial species names can also be abbreviated. For example, *Homo sapiens* can be written *H. sapiens*.

Dichotomous Keys

Figure 7 *Blarina brevicauda* is the only poisonous mammal in Canada. Its venomous bite is not dangerous to humans but can be painful!

dichotomous key a series of branching, two-part statements used to identify organisms (or objects)

Classifying organisms into various taxa with defined criteria provides a framework for identifying organisms. Imagine that you present a taxonomist with a small woodland animal. The taxonomist notes that the animal has four legs and is hairy, so it must belong to the class Mammalia. Its teeth are sharp and needle-like, its eyes are very small, and it has no obvious ears. These features belong to the Order Insectivora, which includes the common shrews and moles. Based on the animal's size and limbs, the taxonomist determines that is it likely a shrew in the Family Soricidae. With even more detailed examination and measurements, she classifies it as a short-tailed shrew, *Blarina brevicauda* (**Figure 7**). You look up the species on the Internet and discover that it is very common in Ontario and is an important member of forest ecosystems. It is also one of the only poisonous mammals on Earth! But what if you want to make the identification yourself, or what if even the expert was not familiar with the characteristics of the particular group of organisms?

Biologists use dichotomous keys to help them identify organisms. A **dichotomous key** is a structure in which a large set of items is broken down into smaller subsets, ultimately leading to the smallest available classification unit (**Figure 8**). At each step in the identification process, the user must choose between two defining statements. Each alternative leads to a result or another choice. Eventually, the key ends with the classification of the organism into a given taxonomic level. As illustrated in Figure 8, a dichotomous key identifies an organism based on the presence or absence of carefully chosen characteristics. These keys can take different forms.

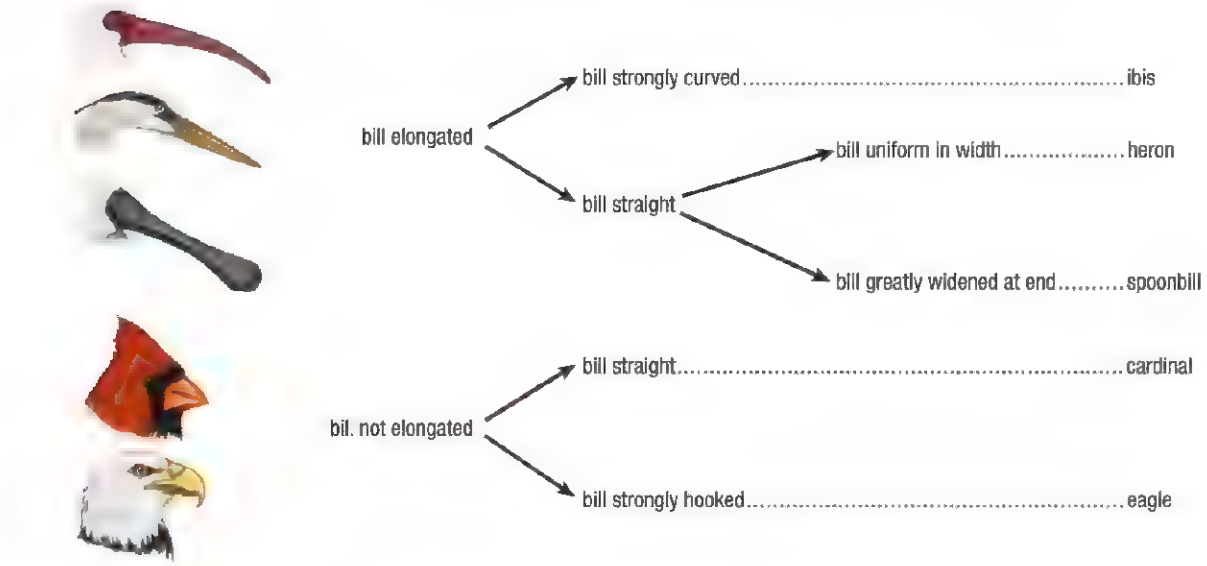


Figure 8 A dichotomous key for classifying birds.

The dichotomous key above provides an easy method of identifying these five bird species. In practice, however, most dichotomous keys used by scientists are more difficult to construct and use. In order to distinguish between each of the thousands of different bird species—there are more than 60 different species of herons alone—the keys must use more detailed criteria. Before scientists construct the key, they must agree on the features that distinguish each species. They must also learn the terminology used to name and describe these features.

Creating and using dichotomous keys to classify other groups of organisms can be even more challenging. For example, many plants can be distinguished from each other only by a dissection and close examination of their flower parts, and this can be done only at certain times of the year. Even with the flowers in hand, scientists need expertise to use a dichotomous key. The glossary of a well-known plant key of North American plants includes more than 800 technical terms, beginning with terms such as *abaxial*, *acaulescent*, *accrescent*, *achene*, and *achlamydeous*.

A key challenge that traditional taxonomists face is deciding and agreeing on what criteria to use to define each taxon. What feature or features should be used as the basis for including one species while excluding another? The choice of criteria is often hotly debated. As a result, there is often significant disagreement about the arrangement of species within taxa.

Once the features to be used in a dichotomous key are chosen, another challenge arises—these features may be difficult to observe. Internal anatomical and physiological similarities, for example, are considered more significant than outward appearances, but they are not always easily observed. For instance, the horseshoe crab has crab-like legs and pincers, but its blood chemistry and internal structures indicate that it is more closely related to spiders than to true crabs (**Figure 9**).

Also, decisions are often influenced and limited by available information, as well as by the interest in a particular group of species. For example, the approximately 9000 species of living birds are traditionally classified into some 160 different families (**Figure 10(b)**). In contrast to this very well studied group, more than 60 000 species of parasitic wasps have been placed in a single family—the Ichneumonidae (**Figure 10(b)**)! Such a dramatic difference highlights some of the challenges and limitations of using classification systems.

Figure 9 Despite its name, the horseshoe crab is more closely related to spiders than to true crabs

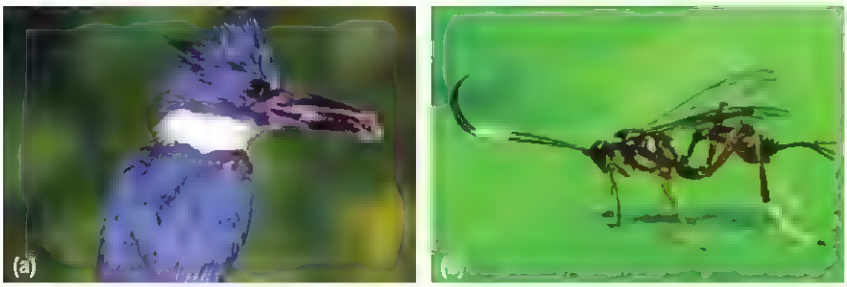


Figure 10 (a) The average bird family taxon contains approximately 50 species. The belted kingfisher is one of only nine species in the family Cerylidae. (b) This wasp is one of more than 60 000 species in the family Ichneumonidae.

As you will learn in the next section, most modern taxonomists no longer use similarity as the basis for grouping organisms. Instead they use the principle of relatedness, which is based on the evolutionary history of a species. This new approach has significant advantages, but many biologists still use the traditional and familiar classification system.

Investigation 1.2.1

Using and Constructing a Dichotomous Key (page 32)

Now that you have read about dichotomous keys, you can comp ete Investigation 1.2.1.

In this observationa study, you will use a dichotomous key to classify fish, and you will create a dichotomous key that can be used to classify insects.

1.2 Summary

- Classification systems are useful, but extremely variable.
- The science of classifying living things is called taxonomy.
- All species are given a unique binomial (two-word) species name.
- Traditional taxonomy groups species together according to shared characteristics.
- Scientists often disagree about the criteria used to group species.
- Traditional taxonomy groups species into a number of major levels, or taxa.
- Dichotomous keys are often used to help identify species.

1.2 Questions

1. Describe four classification systems you have used in the past week. How did they help you? K/U A
2. What is taxonomy? Explain how taxa are arranged in a hierarchy. K/U
3. Use a graphic organizer of your choice to describe the key contributions of Linnaeus to the science of naming and classifying species. Include the term "binomial nomenclature." K/U C
4. Describe the philosophy behind the *scala naturae*. K/U
5. Use the information in **Table 3** to answer the following questions: K/U T/I
   (a) Which two species would you expect to share the greatest number of features?
   (b) Which species would you expect to be least similar to all others?
   (c) What evidence is there that otters share more features with mink than dogs do with cats?
   (d) Predict some probable characteristics of *Alopex lagopus*.

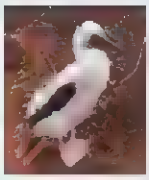
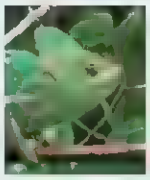
Table 3

Common Name	Order	Family	Scientific Name
orca	Cetacea	Delphinidae	*Orcinus orca*
river otter	Carnivora	Mustelidae	*Lontra canadensis*
mink	Carnivora	Mustelidae	*Neovison vison*
Siamese cat	Carnivora	Felidae	*Felis domesticus*
Labrador retriever	Carnivora	Canidae	*Canis lupus*
	Carnivora	Canidae	*Alopex lagopus*

6. Conduct online research to find out the common name of *Alopex lagopus*. Were your predictions correct? K/U
7. Research the following taxa and answer the questions below.
   (i) Cestoda
   (ii) Cervidae
   (iii) Euphorbia T/I C A
   (a) What is the taxonomic level of the group (phylum, class)?
   (b) What are their key distinguishing features—what criteria are used to define the group?
   (c) How many species are in the group? Provide a few examples.
   (d) Describe the ecological role of the group and any specific relationships to humans.
8. Traditional biological classification systems group species according to shared characteristics. K/U T/I C
   (a) Consider some of the important and obvious characteristics of the species in **Table 4**. Describe some of the problems you might encounter when trying to decide which characteristics to use for grouping.
   (b) Which characteristics would you use for classifying these species? Why?
   (c) Based on your choices, construct a dichotomous key for these species.

GO TO NELSON SCIENCE

Table 4

					
• warm-blooded • hairless, smooth skin • four-chambered heart • swims using flippers and tail flukes • live birth	• warm-blooded • some hair • four-chambered heart • walks on two legs • live birth • no tail	• warm-blooded • feathers • four-chambered heart • walks on two legs • flies • lays eggs • short tail	• cold-blooded • scales • three-chambered heart • walks on four legs • lays eggs • swims using its tail	• cold-blooded • scales • three-chambered heart • walks on four legs • prehensile tail • lays eggs	• warm-blooded • covered in hair • four-chambered heart • no tail • live birth • four limbs used on land and in water

Phylogeny and Modern Taxonomy

1.3

In 1859, Charles Darwin published *On The Origin of Species*, in which he described his theory of evolution. The theory of **evolution** states that all living things are descended from a common ancestor in the same way that family members are related to each other through a common ancestor. The theory describes how this principle applies to different species. When we say that two people are closely related to each other, we are usually thinking in terms of just one or two generations. When biologists say that two species are closely related to each other, they are often thinking in terms of many thousands of generations. Just as some people are much more closely related than others, some species are much more closely related than others.

Taxonomy—the classification, identification, and naming of organisms—aims to group organisms according to a set of criteria. One criterion is how closely related they are to each other.

evolution the scientific theory that describes changes in species over time and their shared ancestry

Phylogeny

Phylogeny is the science that deals with evolutionary relationships between and among species—entire populations of individuals. In many ways, these relationships, or kinships, are similar to a large family tree (**Figure 1(a)**). Only instead of tracing the relationships between individual family members, phylogeny tracks relationships between entire species. These relationships can be presented in a **phylogenetic tree**, a branching diagram used to show the evolutionary relationships between and among species (**Figure 1(b)**).

phylogeny the study of the evolutionary relatedness between, and among, species

phylogenetic tree a diagram depicting the evolutionary relationships between different species or groups

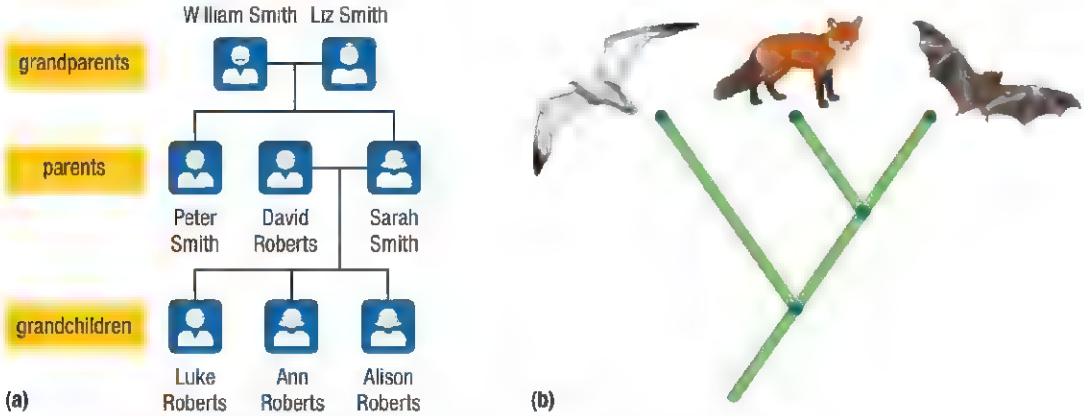


Figure 1 (a) A family tree shows biological relationships between people. Kinships are represented by connecting lines. (b) Phylogenetic trees show the evolutionary relationships among species.

Just as individuals in a family tree are descendants from common ancestors, the groups of organisms in a phylogenetic tree are descendants of common ancestors, too. Most of the evidence for these relationships is based on similarities and differences in physical and genetic characteristics.

Clades

In a phylogenetic tree, species are grouped into clades. A **clade** is a taxonomic group that includes a single ancestor species and all its descendants. Each clade on a phylogenetic tree can be thought of as a branch on the "tree of life." The tips of a branch on a phylogenetic tree can represent a particular species or an entire group of species. Moving back along a branch is like moving back through time.

clade a taxonomic group that includes a single common ancestor and all its descendants

Clades can be small—including only a small number of species that share a very recent common ancestor. For example, the members of the horse family form a particularly small clade (**Figure 2(a)**). Clades can also be large—including all those species that share a more distant common ancestor—such as the order Carnivora of mammals (**Figure 2(b)**). Regardless of their size, clades are based on the most fundamental connection between species: their evolutionary relatedness.

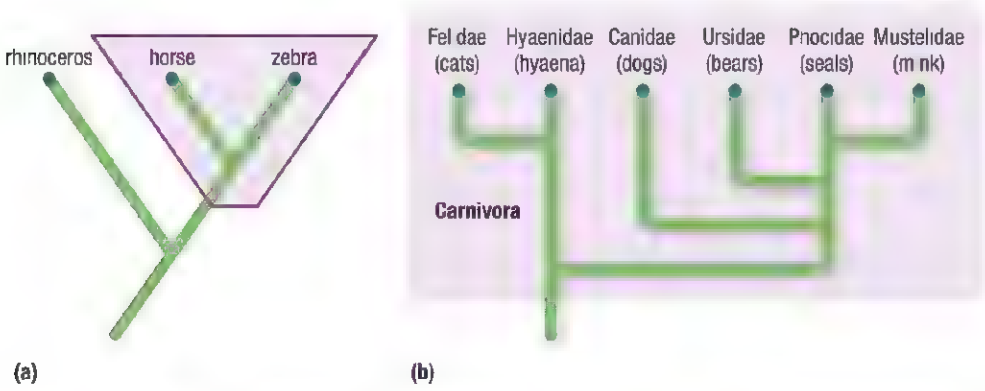


Figure 2 (a) The horse family is a small clade that includes the modern horse and zebra but not the rhinoceros. (b) The order Carnivora is a larger clade that includes many different families and is within the class Mammalia. Note that not all members of each clade are shown.

Tutorial 1 Using Phylogenetic Trees

Phylogenetic trees can be used to infer evolutionary relationships between species, as illustrated by Sample Problem 1. Phylogenetic trees can also be used to identify clades, as you will see in Sample Problem 2.

CASE 1: USING A PHYLOGENETIC TREE TO INFER EVOLUTIONARY RELATIONSHIPS

Sample Problem 1: Interpreting Phylogenetic Trees

Figure 3 shows a simple phylogenetic tree. How closely are the rhinoceros, horse, and zebra related?

Figure 3 A simple phylogenetic tree

Solution:

Step 1. Carefully examine the phylogenetic tree in Figure 3. The species are placed at the tips of the branches across the top of the diagram. The lines, or branches, represent each species' ancestors going back in time.

Step 2. Look at the arrow to the right of the tree. The top of the tree represents the present day. As you follow the branches downward, you are going back in time.

Step 3. To interpret the kinship, or relatedness, of any two species, follow their branches backwards (downward) in time until you reach the place where they meet.

Step 4. Look at the branches for the zebra and the horse. Species A represents their *most recent common ancestor* (**Figure 4.**)

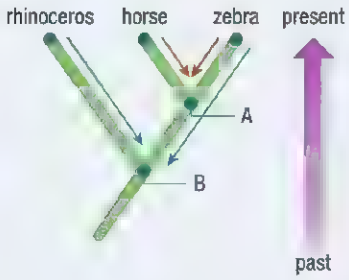


Figure 4 The red arrows trace the ancestors of the horse and zebra until they meet at species A. The blue arrows trace the ancestors of the zebra and rhinoceros until they meet at species B.

Step 5. Look at the branches for the zebra and the rhinoceros. Their most recent common ancestor is species B in Figure 4. Species B is located "further back in time" than species A. This means that the rhinoceros and zebra are more distantly related than the horse and zebra.

Step 6. Note that the horse has the same relationship to the rhinoceros as the zebra does (**Figure 5**). The rhinoceros is just as closely related to the horse as it is to the zebra. Species B is the most recent common ancestor of all three species.

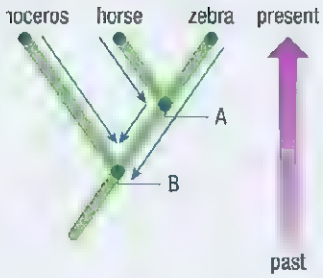


Figure 5 The horse and the zebra have the same relationship to the rhinoceros.

CASE 2: IDENTIFYING CLADES USING PHYLOGENETIC TREES

Sample Problem 2: Identifying Clades Using Phylogenetic Trees

How can phylogenetic trees be used to identify clades? The steps outlined below explain the process.

Step 1. **Figure 6** shows two clades. The horse family clade (outlined in purple) includes species A and all its descendants. The rhinoceros is not a member of this clade because it is not a descendant of species A.

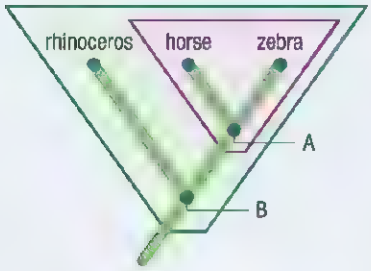


Figure 6 Clades can be part of larger clades.

Step 2. Look at the green outline in Figure 6. All three species are in this larger clade, which includes all the descendants of species B.

Step 3. Look at **Figure 7**. Phylogenetic trees can portray any number of different groups. This tree shows the evolutionary relationships of a few familiar mammals. Note that the species outlined in orange form a clade. The species outlined in green do *not* form a clade. The most recent common ancestor of the bat and seal is species D. However, the rat, rabbit, and monkey are also descendants of species D, so they must be included in any clade that includes species D.

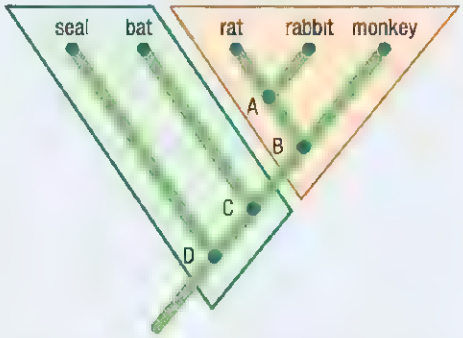


Figure 7 The species that are outlined in green do not form a clade.

Practice

1. Sketch Figure 1(b) (page 21) in your notebook and answer the following questions. K/U T/I C A
   (a) Indicate the location of the species that is
      (i) the most recent common ancestor of foxes and bats
      (ii) the most common recent ancestor of all three species
   (b) Based on this tree, is a bird more closely related to a fox or to a bat? Explain your reasoning.
2. (a) In your notebook, sketch the phylogenetic tree in Figure 7, above. Do not include the coloured outlines. Use different colours to show the following clades: K/U T/I C A
      (i) the smallest clade that contains the bat and rabbit
      (ii) the smallest clade that contains the seal and the rat
   (b) What is the maximum number of unique clades (of any size) that can be found in this tree?

Taxonomy Today

One of the major strengths and weaknesses of the traditional classification system is that it groups species primarily by observed morphological characteristics. These groups are then arranged into a set number of taxonomic ranks. Grouping species this way is simple and convenient but may overlook less obvious characteristics that often provide strong evidence about relatedness.

In contrast, phylogenetic analysis can uncover the evolutionary relatedness of organisms (**Figure 8**). The organisms are grouped into different-sized clades that are not limited to a set number of taxonomic ranks. One challenge of using this system is uncovering evolutionary relatedness that may go back millions of years—a task that may require detailed analysis of both fossil and genetic evidence.

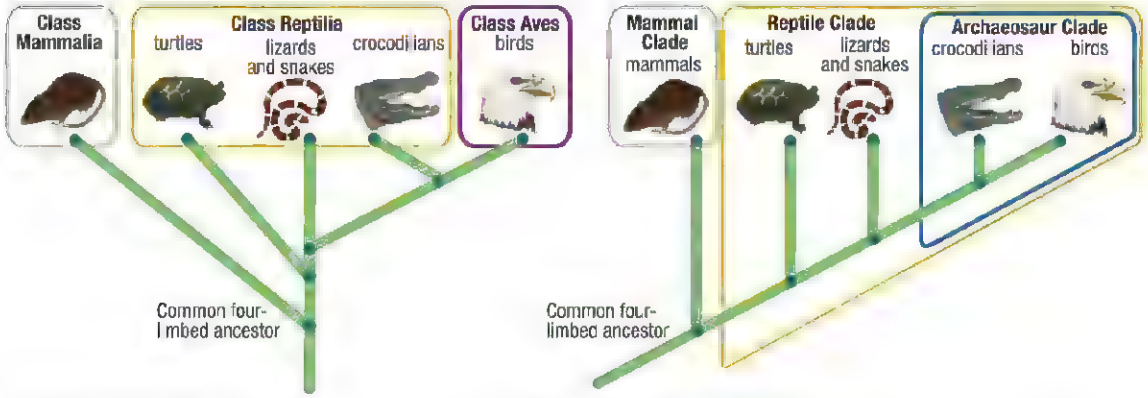


Figure 8 In the (a) traditional classification system, crocodiles are grouped with turtles, snakes, and lizards because of their shared physical features. In (b) modern taxonomy, crocodilians are grouped with birds because they share a more recent common ancestor. Both birds and crocodilians are included in the larger reptile clade.

The International Barcode of Life Project

Modern genetics is providing taxonomists with a powerful new tool for identifying species. DNA barcoding was first proposed by Paul Herbert, a researcher at the University of Guelph. The idea is to use DNA technology to create a DNA profile of every species in the form of a barcode. Ultimately researchers in the field will be able to use a handheld device to immediately identify any species from a tiny sample of DNA (**Figure 9**). This will have tremendous benefits. Because DNA is found in all cells the identification system can be used on organisms at any stage of their life, from egg to adult, and can even be used to identify tissue samples such as hair, feathers, or meat. This can be a very useful tool for controlling the trafficking in products made from endangered species.

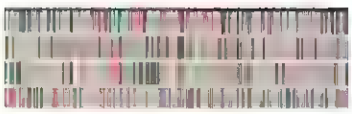


Figure 9 The barcode for the frog-eating bat *Trachops cirrhosus*.

The International Barcode of Life Project (iBOL) was launched in 2010. It is supported by 25 countries and involves hundreds of leading research scientists. The project's hub will be at the Biodiversity Institute of Ontario at the University of Guelph.

Dr. Herbert's lab has already used DNA barcoding technology to reveal widespread false labelling of fish products sold in Canada and the U.S. Investigative journalists bought 153 samples of fish from grocery stores across Canada. DNA testing revealed that 34 of the samples were mislabelled. For example, fish labelled as wild caught coho salmon was actually farm-raised Atlantic salmon, and fish labelled as cod was actually haddock.

WEB LINK

To learn more about the International Barcode of Life Project,

GO TO NELSON SCIENCE

Eventually DNA barcoding technology may allow for very low cost routine sampling and monitoring of species diversity in entire ecosystems. As of November 2010 a barcode database had already been created for about 90 000 species.

Today, taxonomists choose different methods for classifying organisms. Some are "purists," basing classifications strictly on phylogenetic relationships. Others still prefer to group species by more easily recognizable features. Throughout the rest of this

unit, you will have opportunities to use your understanding of both traditional and modern classification systems to examine the major groups of Earth's organisms. For convenience, we may use the names of the traditional ranks to describe groups. You will also explore some surprising evolutionary relationships between some of the most well known groups of organisms.

CAREER LINK

Taxonomist

Taxonomists are scientists who specialize in the identification and classification of species. To learn more about a career as a taxonomist,

GO TO NELSON SCIENCE

1.3 Summary

- Modern biological classification is based on phylogeny—the evolutionary relatedness of species.
- A clade is a taxonomic group that includes all the descendants of a common ancestor.
- Phylogenetic trees are used to show evolutionary relationships among species and groups.
- Both traditional and phylogenetic classification systems have advantages and disadvantages.

1.3 Questions

1. Why is a classification system based on relatedness more objective than a classification system based on the comparison of observed characteristics? K/U
2. Clades can be described as "natural groups." Why do you think this is so? T/I
3. What do the "tips" and "branches" of a phylogenetic tree represent? K/U
4. Describe how you "trace ancestors back through time" on a phylogenetic tree. K/U
5. Compare and contrast traditional and phylogenetic classification systems. K/U T/I
   (a) What are the advantages and disadvantages of each?
   (b) Think of an example of when it would be useful to use a traditional classification. Why would this system be the best choice in this case?
   (c) Think of a situation where it would be useful to use a phylogenetic classification system. Why would this system be the best choice in this case?
6. Traditional and phylogenetic classification systems *usually* place species in the same groups. For example, both systems place lions and tigers together, and horses and zebras together. Why is this not surprising? K/U T/I
7. Sketch a simplified version of the phylogenetic tree from Figure 8(b) (page 24) in your notebook. T/I C A
   (a) Place the letter "A" at the location that represents the most recent common ancestor of mammals and lizards.
   (b) Are mammals more closely related to one taxonomic group than any other? Explain.
   (c) The closest relatives of crocodiles are birds. Why do you think traditional taxonomists place crocodiles in the same class as turtles, lizards, and snakes?
8. Brainstorm why an understanding of phylogenetic analysis might be useful to scientists working to preserve biodiversity. T/I A
9. Sketch the phylogenetic tree in **Figure 10** in your notebook. T/I C

Figure 10 A phylogenetic tree

   (a) Which coloured groups represent a clade? Explain.
   (b) Are the orange groups more or less closely related to the green groups than they are to the pink groups? Explain.
   (c) Place a letter "X" on the tree to represent the most recent common ancestor to all the orange and green groups.
   (d) Circle three true clades that occur *within* the green box.
10. Examine Figure 2(b) on page 22 and answer the following questions. K/U T/I
   (a) The Mustelidae family includes both mink and otters. Both of these species spend most of their time in the water. Using evidence from the phylogenetic tree, explain why this makes sense.
   (b) In your opinion, does a bear seem more similar to a dog or to a seal? Consider its physical appearance, ecological niche, and behaviour.
   (c) Is a bear more closely related to a seal or to a dog? How do you know?
   (d) Evolutionary changes do not occur at the same rate in different groups. How might this help explain your answer to (c)?

1.4 Kingdoms and Domains

prokaryote a single-celled organism that does not contain membrane-bound organelles

eukaryote any organism whose cells contain organelles; some eukaryotic organisms are single-celled, while others are multicellular

The Linnaean classification system recognized only two kingdoms of living things—Animals and Plants. When biologists began to use microscopes, they discovered many new micro-organisms and gained a better understanding of the cellular structure of living things. Biologists discovered **prokaryotes**—unicellular organisms, such as bacteria, that do not have membrane-bound organelles. They also discovered many new **eukaryotes**—unicellular and small multicellular organisms with organelles. These organisms were called protists—their cells had a nucleus and other organelles but showed an extraordinary diversity of shapes, sizes, and life cycles. Biologists also began to see evidence of significant differences between plants and fungi.

Today, most biologists classify the more than 1.7 million known living species into six kingdoms. As you will learn, these six kingdoms are grouped within a higher taxonomic rank.

Kingdoms of Life

Figure 1 shows a typical representation of the six kingdoms of life. The most easily recognizable kingdoms are the Animals, Plants, and Fungi. These kingdoms include many large multicellular organisms. The other kingdoms include mostly or entirely microscopic single-celled, or unicellular, organisms. The eukaryotic Protista is by far the most diverse group of organisms. Many of these are tiny, single-celled organisms such as amoeba and paramecium, while others, such as the kelps, are among the largest living organisms. The Eubacteria, which are commonly called "bacteria," and Archaea are prokaryotic and are often extremely difficult to distinguish due to their extremely small size and lack of internal structure. Most prokaryotes consist of individual cells, but some others consist of many cells that have joined to form long strands or clustered arrangements.

LEARNING TIP

Name Change
Archaea used to be called *Archaebacteria*, but we now know that they are distinct from Eubacteria, the "true bacteria."

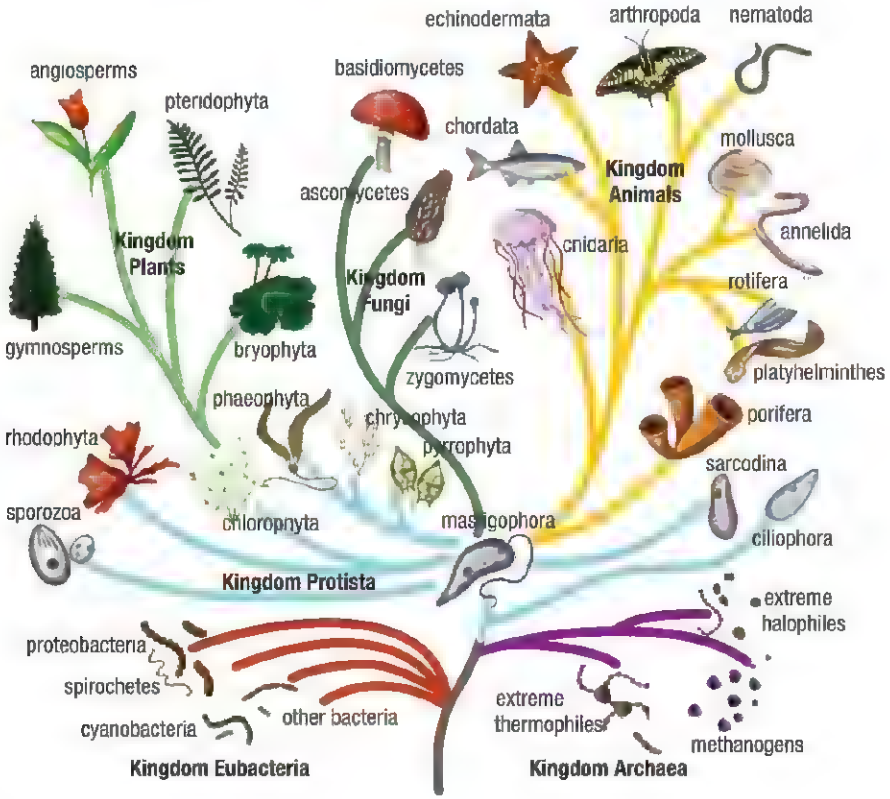


Figure 1 The six kingdoms of life

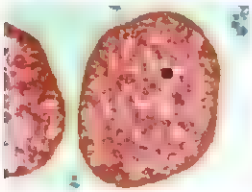
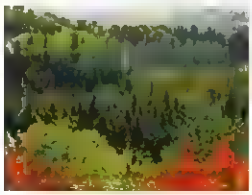
You should note that the relative size of each kingdom in most diagrams, including Figure 1, does not represent the diversity, sheer numbers, or evolutionary relationships of the various kingdoms. The Animal, Plant, and Fungi kingdoms are usually greatly exaggerated in size. This reflects our own interest in these groups as well as our familiarity with them in our everyday life.

Table 1 gives an overview of key characteristics of the six kingdoms. Keep in mind that there are exceptions to these general descriptions and that the number of different species of micro-organisms is likely grossly underestimated.

UNIT TASK

Which kingdom or kingdoms do the organisms in your chosen group belong to?

Table 1 Common Characteristics of the Six Kingdoms of Life

Kingdom	Cell characteristics	Other characteristics	Examples (Organisms shown in the photos are bolded.)	
Eubacteria > 10 000 described species	• Prokaryotic • Cell walls contain a unique compound. • Cells are variable in shape and size.	• Diverse means of obtaining energy and nutrients—photosynthetic, chemotropic, or heterotrophic • All can reproduce asexually	***Escherichia coli***, *Salmonella*, nitrogen-fixing bacteria	
Archaea > 400 described species	• Prokaryotic • Cell walls and cell membranes have a unique structure. • Most are extremely small.	• Some colonize extreme environments. • Live in the digestive tracts of mammals and marine environments • All can reproduce asexually.	**extreme thermophiles** (organisms that thrive at high temperatures), methanogens (micro-organisms that produce methane as a byproduct)	
Protista > 100 000 described species	• Eukaryotic • Cells have extreme diversity of cellular structure. • Some have chloroplasts and cell walls.	• May be heterotrophic or photosynthetic, or both • Have variable forms of movement • Usually live in aquatic or other moist environments • Reproduce sexually and asexually	***Amoeba***, kelps, green algae	
Fungi > 100 000 described species	• Eukaryotic • The cell wall is composed of chitin. • Most are multicellular. • Cells have no chloroplasts.	• All are heterotrophic • Most are terrestrial • Reproduce sexually and asexually	**mushrooms**, yeasts, moulds	
Plants > 250 000 described species	• Eukaryotic • All are multicellular • Cell walls are composed of cellulose. • Possess chloroplasts	• Autotrophic and photosynthetic • Most are terrestrial • Reproduce sexually and asexually	mosses, ferns, **conifers**, flowering plants	
Animals > 1.2 million described species	• Eukaryotic • All are multicellular. • Cells have no cell walls or chloroplasts.	• All are heterotrophic • Most reproduce sexually. • Live in terrestrial and aquatic environments	**elephants**, sponges, corals, insects, snails, birds, humans	

A simplified phylogenetic tree (**Figure 2**) shows key evolutionary relationships among the six kingdoms. Note that the Protist Kingdom does not represent a single clade. The brown, red, and green algae are more closely related to plants, while the amoeboid protists are more closely related to fungi and animals.

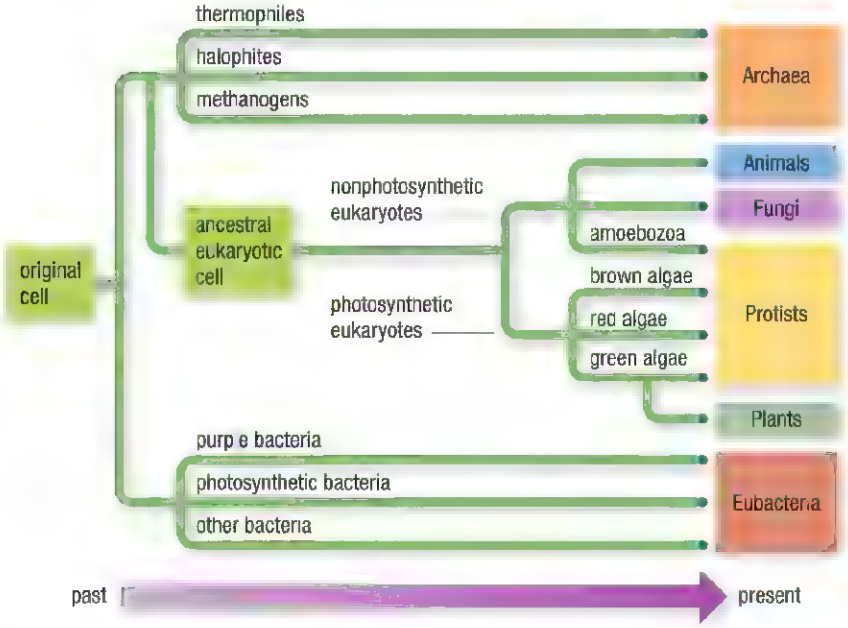


Figure 2 A simplified phylogenetic tree of the six kingdoms

Domains of Life

domain the highest taxonomic level; there are three domains of life

In 1996, Carl Woese conducted a detailed analysis of living organisms. He revealed that all organisms could be classified into three distinct groups. These groups, called **domains**, showed significant differences in their genetic makeup, which was very compelling evidence of their distinct evolutionary kinships (**Figure 3**).

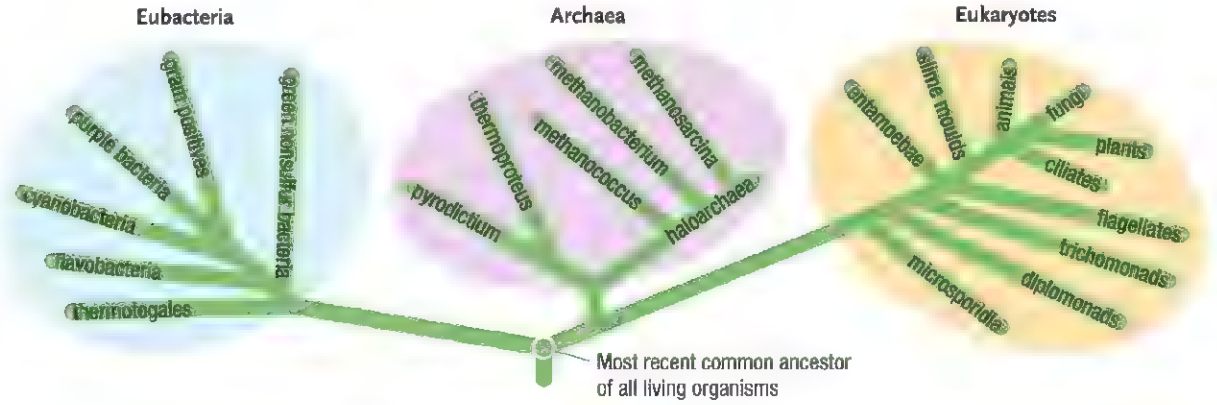


Figure 3 The three domains of life based on the work of Carl Woese. This detailed arrangement of the branches is continually being refined as new data become available.

The Domain Eubacteria contains only the Kingdom Eubacteria. Similarly, the Domain Archaea contains only the kingdom Archaea. The third domain, Eukaryotes, contains the other four kingdoms: Protista, Animals, Plants, and Fungi. The branches of the tree and the distances between the branches show an estimate of how closely related the groups are. You may be surprised to see that, while there are very dramatic differences in the physical appearances of animals, plants, and fungi, they were all placed very close together on this tree. The proximity is determined largely by comparing the genetic makeup of different species and groups.

Investigation 1.4.1

Sampling the Diversity of Life (page 32)
After reading about Kingdoms and Domains, you can complete Investigation 1.4.1.

In this field study, you will sample and then classify organisms from a chosen ecosystem.

Research This

Who Is in My Clade?

Skills: Researching, Analyzing, Communicating

SKILLS HANDBOOK A2.1

Taxonomists have studied the phylogenetic relationships of all well-known groups of organisms. Their findings are often presented in the form of phylogenetic trees. In this activity you will examine the phylogenetic relationships of a species of your choosing. You should choose a relatively well known mammal or bird, since you are more likely to be familiar with its related groups.

1. Choose a species and describe its distinguishing characteristics. Using the Internet and other resources, find out its genus name.
2. Research the names and characteristics of all other species that are in the same genus.
3. Find out which taxonomic family and order your species belongs to. List the names of several other species that are in the same order.
4. Find two or three simple phylogenetic trees that illustrate the relationships among these species and clades that your chosen species belongs to. Draw your own version of the tree based on the information you have found. Be creative, but present your findings accurately.

A. How similar were members of the same genus? What features do they share? What features can be used to tell them apart? K/U T/I

B. List and describe a number of other species to highlight the diversity within the same order. K/U T/I

C. Based on your research, which groups within the order are most closely related? K/U

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1.4 Summary

- Most biologists classify living things using a system of six kingdoms and three domains.
- The most easily recognized kingdoms are Animals, Plants, and Fungi.
- Protista is the only kingdom that does not represent a clade.
- Eubacteria and Archaea are difficult to distinguish because of their extremely small size and lack of internal structure.
- The six-kingdom, three-domain system is based on phylogenetic relationships revealed by genetic evidence.

UNIT TASK BOOKMARK

To which domains do the organisms in your chosen group belong?

1.4 Questions

1. List the six kingdoms and three characteristics of each. K/U
2. Why do you think biologists originally placed fungi within the plant kingdom? K/U T/I
3. Use the simplified phylogenetic tree in Figure 2 (page 28) to answer the following questions: K/U T/I C
   (a) State the four groups that gave rise to the protists.
   (b) To which other group(s) are the Amoebozoa most closely related?
   (c) Suggest some possible reasons to account for why biologists have grouped the Amoebozoa with brown, red, and green algae in the kingdom Protista.
   (d) Are animals more closely related to the Archaea or to the Eubacteria? Explain your reasoning.
4. Make a simple sketch of a "tree of life" that includes six kingdoms. Label the kingdoms but colour the branches according to domain. Use a different colour for each domain. K/U C
5. Describe the most significant differences between the three domains of life. Why are the Eubacteria and Archaea difficult to distinguish? K/U C

1.5 — *Biology* JOURNAL —

Birds—In a Class of Their Own

ABSTRACT

While birds have many unique and easily distinguished features, they are challenging to classify compared with other major groups. Fossil evidence links them closely with a group of carnivorous dinosaurs. Morphological and genetic evidence suggests that their closest living relatives are the crocodiles. Both the traditional and modern classifications of birds have advantages and disadvantages.

SKILLS HANDBOOK A4

Modern Birds

Birds are among the most easily distinguished of all animals. They are covered in feathers and have powerful wings and beaks (**Figure 1(a)**). Unlike most other vertebrates, birds lay hard-shelled eggs. Like mammals, birds are warm-blooded and have a four-chambered heart. Birds also show complex behaviours that distinguish them from many other groups of animals. Most birds construct nests, incubate their eggs, and feed and care for their young.

Such distinctive features make birds easy to distinguish as a group but make it difficult to uncover their phylogenetic relationships. Taxonomists have wondered how birds should be classified: what other major groups of living animals are birds most closely related to?

Birds share some morphological features with reptiles: both have some similar skeletons and both have scales on all or parts of their body (**Figure 1(b)**). This and the other physical evidence support the hypothesis that birds might be closely related to reptiles.

Figure 1 (a) An adult Hoatzin. Young chicks have a claw on each wing, which they use for climbing trees to escape from predators. (b) Birds have reptile-like scales on their legs and toes.

Feathers & Fossils

Discovered in 1861, *Archaeopteryx* was one of the first fossils of a feathered animal. *Archaeopteryx* lived about 145 million years ago. It had wings with prominent flight feathers and a reptile-like jaw with many small teeth. The fossil was more evidence that linked birds more closely to reptiles than to other vertebrates. The fossil also showed features that were shared with another well-known group of fossilized reptiles—the dinosaurs. The discovery challenged taxonomists.

Since 1861, a great many dinosaur fossils have been discovered, but it was only recently that many beautifully preserved fossils of feathered animals were unearthed in northeastern China.

Since 1990, fossils of more than 20 different species of feathered animals have been discovered—almost all of them belonging to the theropod group of dinosaurs. The theropods are a well-known group of bipedal carnivores that includes *Tyrannosaurus* and *Velociraptor*. These feathered dinosaurs include species that clearly did not fly, as well as some that did (**Figure 2**).

This new wealth of fossil evidence has provided biologists with compelling evidence that birds are very closely related to theropods. Today, most biologists consider birds a group of living dinosaurs!

Figure 2 One of the oldest fossils of a bird-like dinosaur is *Anchiornis huxleyi*. This artist's depiction is based on well-preserved fossils.

The Question of Crocodiles

In addition to this dinosaur link, evidence also suggests a strong connection between birds and an unusual group of living reptiles—the crocodiles.

The crocodile group, or crocodilians, includes the well-known alligators and crocodiles, as well as a number of other closely related species.

Crocodiles share many features with birds that they do not share with other reptiles. Crocodilians are the only

reptiles with four-chambered hearts. They have skeletal features shared only with dinosaurs and birds, such as a more upright positioning of their legs. They are also among the very few reptiles that care for their young.

This evidence creates a taxonomic dilemma. Should crocodiles be considered reptiles if they are actually more closely related to birds than they are to lizards, snakes, and turtles (**Figure 3**)? And if crocodiles are classified as reptiles, does that mean birds should be classified this way, as well?

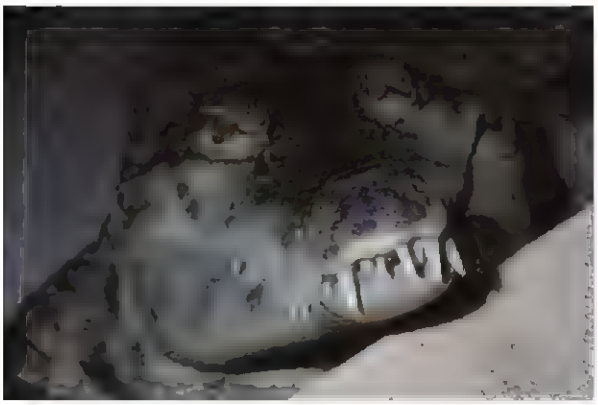

Figure 3 Crocodilians are more genetically similar to birds than to any group of reptiles.

Clade or Class?

Based on birds' distinct features, traditional taxonomists placed them in their own taxon—class Aves.

The phylogenetic tree in **Figure 4** is based on the most recent scientific evidence. It shows the evolutionary relationships between birds and other groups of four-legged vertebrates. The figure includes traditional taxonomic names and groupings (the orange boxes). Based on this tree, species A is the most recent common ancestor of all the traditional reptiles—turtles, lizards and snakes, crocodilians, and the extinct dinosaurs. However, birds are also direct descendants of species A and therefore would be placed in the same clade. Based on phylogeny, class Reptilia is not a valid taxon unless the birds are included.

There are advantages and disadvantages to both approaches. Modern phylogeny avoids the odd situation of separating the most closely related groups into different taxa. On the other hand, the traditional system recognizes the many distinctive and important features of birds as being reason to separate birds into a class of their own.

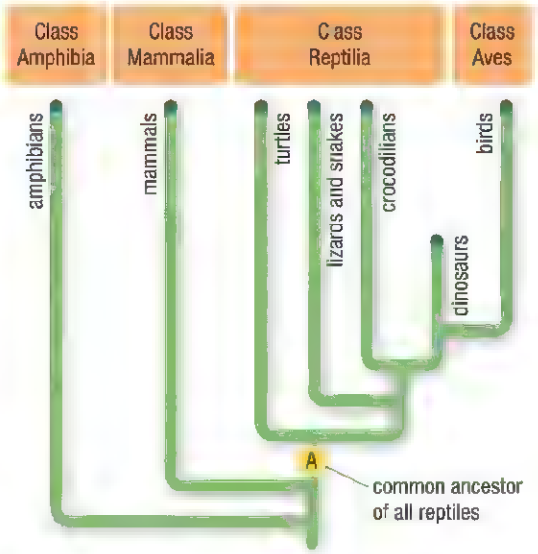

Figure 4 In traditional taxonomy, birds and crocodiles are placed in different classes. But based on phylogeny, they are the two most closely related of the living groups in this phylogenetic tree.

Advances in scientific understanding are ongoing and often involve differences of opinion. Without the accumulation and analysis of many pieces of evidence, it is highly unlikely that anyone would have hypothesized that birds were living dinosaurs, or that birds were the closest living relatives of crocodiles.

Further Reading

Attenborough, David. (1998) *The Life of Birds*. Princeton, NJ: Princeton University Press.

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1.5 Questions

1. Based on the phylogenetic tree in Figure 4, answer the following questions:
   (a) Are lizards more closely related to turtles or to birds?
   (b) Are mammals more closely related to turtles or to birds? K/U T/I
2. All scientific knowledge is considered open for revision. Use the example of bird phylogeny to explain how the accumulation of evidence refined scientific understanding. K/U T/I
3. Scientists have recently completed the following pieces of research: T/I A
   - a comparison of the respiratory systems of birds and crocodiles (birds are unusual in having a one-way flow of air through the main passages within their lungs)
   - a comparison of the proteins found in the connective tissues of various reptiles and birds with that of a sample extracted from a *Tyrannosaurus rex* fossil

   (a) Make predictions regarding their findings.
   (b) Research the findings of these investigations. Were your predictions correct?

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CHAPTER 1 Investigations

Investigation 1.2.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Using and Constructing a Dichotomous Key

Dichotomous keys can be used to help identify and classify a set of unfamiliar organisms. In a dichotomous key, paired statements offer choices about the presence or absence of specific characteristics.

Purpose

To use a dichotomous key to classify fish belonging to the taxonomic class Chondrichthyes and to construct a dichotomous key to identify insects

Procedure: Part A

Using a Dichotomous Key

1. Use **Figure 1** as a reference to help you identify the body structures of cartilaginous fish (fish with a non-bony skeleton) referred to in the dichotomous key.
2. The observations for Part A of this activity are below (**Figures 2** to **7**). Carefully examine the images.
3. Use the dichotomous key (**Table 1**) to identify the cartilaginous fish in Figure 2. Start by reading Step (i) of the key. Select the statement in Step (i) that matches the features of the fish you are trying to identify. Then follow the "Go to" direction that corresponds to that statement. Continue making choices until you have identified the fish. Be sure to record the taxonomic order of each fish.
4. Repeat Step 3 for each of the fish shown in Figures 2 to 7.

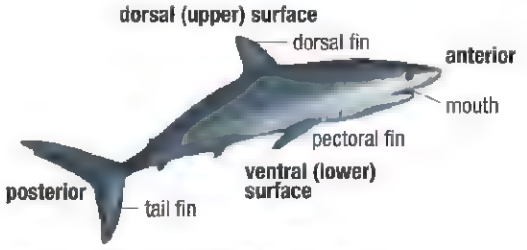

Figure 1 Body structures of cartilaginous fish

Observations: Part A

Use the following images and descriptions of cartilaginous fish as your observations for Part A.

Figure 2

Figure 3

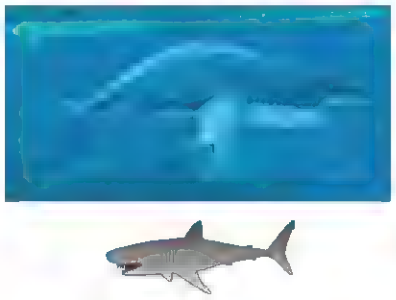

Figure 4

Figure 5

Figure 6

Figure 7

Table 1

Dichotomous Key to Selected Cartilaginous Fish	
i	body with flat dorsal and ventral surfaces ... order Myliobatiformes ... go to ii
	body not noticeably flattened ... order Selachii ... go to iv
ii.	mouth opens anteriorly ... manta ray
	mouth located on ventral surface ... go to iii
iii.	tail relatively stocky without a stinging spine ... barndoor skate
	tail slender and whip-like with stinging spine ... stingray
iv.	head dramatically flattened and wide ... hammerhead
	head not dramatically flattened ... go to v
v.	mouth gaping, no prominent teeth ... basking shark
	mouth moderate in size, many large cutting teeth ... great white shark

Procedure: Part B

Constructing a Dichotomous Key

5. The observations for Part B of this activity are shown in **Figures 8** to **13**. Working with a partner, decide on a creative binomial species name for each of the insects shown.
6. Create a dichotomous key that could be used to identify each species in Figures 8 to 13.
7. Exchange your dichotomous key with another group in the class and use each other's keys to properly identify the species according to the other group's assigned names.

Observations: Part B

Use Figures 8 to 13 as your observations for Part B.

Analyze and Evaluate

(a) List all the features, or characteristics, that you used in Part A to distinguish the fish from each other. K/U

(b) Do you think the same features you listed in (a) could be used in a key to identify all cartilaginous fish? Explain your reasoning. K/U T/I A

(c) How might a biologist benefit from using a dichotomous key with more detailed "choice statements"? K/U T/I A

(d) In Part B, how successful were the dichotomous keys created by your group and other groups in the class? If the keys were not successful, suggest one or two reasons why. K/U T/I

Apply and Extend

(e) Once biologists correctly identify an organism, they can research the species to see if it might be of special interest. Use online resources to learn more about the barndoor skate and the manta ray, two types of cartilaginous fish. Why might a biologist be particularly interested in one or both of these species? K/U T/I A

(f) Some species are easier to identify than others. Suggest some reasons for this. Brainstorm several species that you think are most difficult to tell apart. T/I A

(g) Research the scientific names for each of the insect species in Part B. As part of your research, give the English meaning of each Latin name. T/I C

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Figure 8

Figure 9

Figure 10

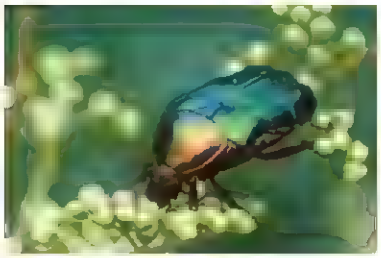


Figure 11

Figure 12

Figure 13

Investigation 1.4.1 FIELD STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Sampling the Diversity of Life

Scientists have identified close to two million different species on Earth. Although some living things are easy to find, many are difficult to identify. Organisms come in all shapes and sizes some are large and mobile; others are microscopic in size and difficult to see. The varied characteristics of organisms make field collection and identification a challenging task.

In this field study, you will choose a number of techniques to sample organisms from a chosen ecosystem. You will then use dichotomous keys and field guides to identify specimens.

Purpose

To collect and identify living organisms using appropriate sampling techniques and equipment

Study Design

In a group, you will use a variety of techniques to sample organisms from an ecosystem of your choice. Before beginning your field work, investigate what sampling techniques are available to you and gather the necessary equipment. Note that some species, such as birds, may be identified in the field through direct observation.

There are many inventive sampling techniques available for collecting different types of organisms. For example, various sizes of nets, dredges, and minnow traps can be used to sample an aquatic environment. Pitfall and sticky traps, sweep nets, and even black lights may be useful for collecting terrestrial insects. Some interesting traps can be made at home (**Figure 1**). Most plants can be sampled using just a pair of pruning shears.

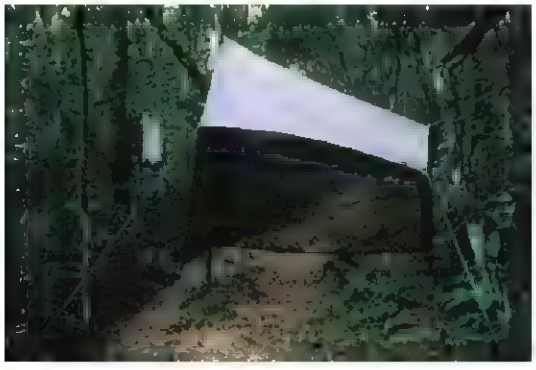


Figure 1 Many insect traps, such as this malaise trap, can be made at home.

You must consider how you will handle and observe your specimens. Will you capture live specimens and bring them back to the lab for identification? Will you attempt to identify some or all of your specimens in the field? Remember to respect the ecosystem you are working in—be gentle with the plants and animals you collect, and if possible return them to where you found them. Do not collect more than you need to.

You will also need an appropriate set of field guides and/or dichotomous keys to use in identification.

Equipment and Materials

- approved sampling equipment
- equipment for safe handling of organisms, such as gloves and suitable containers
- dissecting microscopes, magnifying lenses, and binoculars as needed
- markers and tags
- field guides and dichotomous keys
- notebook and pencil
- digital camera (optional)

Procedure

1. As a group, decide on a suitable sampling location to conduct your field study. If you are not going as a class, obtain your teacher's approval before finalizing your plans.
2. Research sampling devices that are available for collecting specimens from an ecosystem such as the one you have chosen for your field study. Choose two or more methods that you will use in your field work.
3. Seek approval from your teacher before acquiring or constructing the necessary equipment.
4. Organize all the equipment and materials you will need to take into the field. Be prepared for poor weather, strong sun, and the possibility of biting flies.
5. When you arrive at your chosen field location, be sure to orient yourself and inspect your surroundings. Note any potential danger or safety hazards. If necessary, adjust your plans to avoid them.

Alert your teacher if you have any medical conditions that may be affected by your field work.

6. Perform your field work, being careful to avoid contact with potentially irritating organisms.

Handle all organisms with care. Some animals can bite or sting. Many plants are toxic if ingested or may trigger an allergic reaction. Learn to recognize and avoid poison ivy and giant hogweed (**Figure 2**). Do not taste any of the samples you collect. Your teacher will provide safety instructions specific to your chosen site.

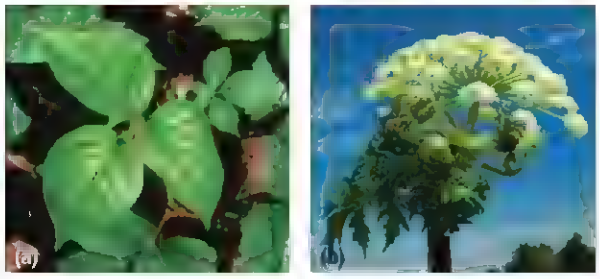


Figure 2 (a) Poison ivy produces an oil that can be extremely irritating. Avoid contact. Poison ivy has leaves in the form of three shiny almond-shaped leaflets. (b) Giant hogweed is a large plant with big, deeply divided leaves. Its clear watery sap can cause severe irritation, burns, and scarring.

7. Record the time and location of the specimens you collect, noting any unusual circumstances. When possible, consider photographing or making sketches of your specimens and releasing them unharmed. These are your "collection notes." Be sure to label each specimen so that it can be matched to your collection notes.
8. If possible, document all of your work with a digital camera. Photograph your sampling equipment setup and your sampling locations. Keep detailed notes of your activity in a field notebook. If a camera is not available, sketch your location and equipment in your notebook.
9. Use field guides and/or dichotomous keys to identify your specimens to the lowest taxa you can. Do this in the field or back at the lab.
10. Consider creating a website to post and share images of your specimens. A website could be used to collaborate on the identification of species with students in other classes or even other schools.

Observations

When making your collections and identifications, be sure to accurately record all of your observations in an appropriate format. Include information about the time and location each specimen was collected as well as the collection method you used.

Analyze and Evaluate

(a) Prepare and submit a complete write-up of your field study. Your write-up should include
   (i) a detailed description of your location and sampling methodology
   (ii) photographs and/or illustrations of your location and the sampling equipment in the field
   (iii) a specimen list and images, if available, including the name or taxon, sampling method, date, and location
   (iv) a discussion section in which you describe your field experience studies, being sure to describe the successes and challenges you faced and including recommendations for future field work T/I C

(b) Discuss your sampling techniques with other groups. What successes and difficulties did they have? Which new techniques would you like to try if you repeated this activity? Summarize your findings in your notebook. T/I C

Apply and Extend

(c) Why do you think it is necessary to use a wide variety of sampling equipment to assess the diversity of an ecosystem? T/I

(d) Do you think there is a bias in a biologist's ability to sample living organisms? Do you think all types of organisms are likely to be fairly represented in field collections? Explain your thinking. T/I C

(e) Which kinds of organisms do you think are most difficult to identify? Why? T/I

(f) New species are continuously being discovered. Use the Internet and other available resources to find out about some of the most recent discoveries of new species. Report your findings back to the class. T/I C

GO TO NELSON SCIENCE

CHAPTER 1 SUMMARY

Summary Questions

1. Create a study guide based on the Key Concepts listed at the beginning of the chapter on page 6. For each point, create three or four subpoints that provide further information, relevant examples, or explanatory diagrams.
2. Return to the Starting Points questions at the beginning of the chapter on page 6. Answer these questions using what you have learned in this chapter. Compare your answers with those that you gave at the beginning of the chapter. How has your understanding changed? What new knowledge and skills do you have?

Vocabulary

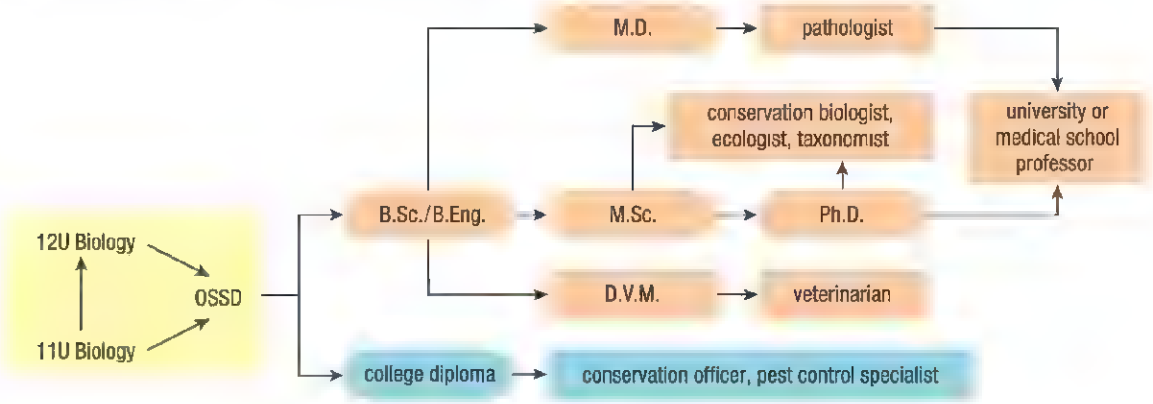
biodiversity (p. 8)
species (p. 8)
hybridization (p. 8)
morphology (p. 8)
evolutionary change (p. 9)
genetic diversity (p. 9)
heterotroph (p. 10)
autotroph (p. 10)
species diversity (p. 10)
structural diversity (p. 10)
biological classification (p. 14)
taxonomy (p. 15)
botanist (p. 16)
genus (p. 16)
binomial nomenclature (p. 16)
taxon (p. 17)
kingdom (p. 17)
dichotomous key (p. 18)
evolution (p. 21)
phylogeny (p. 21)
phylogenetic tree (p. 21)
clade (p. 21)
prokaryote (p. 26)
eukaryote (p. 26)
domain (p. 28)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a Bachelor of Science (B.Sc.) degree. Others require specialized or post-graduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select an interesting career that relates to biodiversity. Research the educational pathway you would need to follow to pursue this career.
2. What are the key tasks and responsibilities of an individual in the career you selected? What do you think makes the career most interesting and challenging?



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CHAPTER 1 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which of the following is true of heterotrophs? (1.1) K/U
   (a) They include all organisms.
   (b) They include only single-celled organisms.
   (c) They cannot make their own food.
   (d) none of the above
2. The range of physical sizes, shapes, and distribution of individuals, as well as habitats and communities in an ecosystem, are together referred to as what? (1.1) K/U
   (a) structural diversity
   (b) species diversity
   (c) genetic diversity
   (d) evolutionary diversity
3. The binomial nomenclature system uses a two-name format. What does the first of the two names refer to? (1.2) K/U
   (a) the specific name
   (b) the genus name
   (c) the species name
   (d) the evolutionary name
4. Which of the following is the most accurate job description of a botanist? (1.2) K/U
   (a) a scientist specializing in the study of marine life
   (b) a scientist specializing in the study of plants
   (c) a scientist specializing in the study of cells
   (d) a scientist specializing in the classification of organisms
5. Which term describes a taxonomic group that includes a single ancestor species and all its descendants? (1.3) K/U
   (a) prokaryote
   (b) classification
   (c) clade
   (d) domain
6. What does a phylogenetic tree show?
   (a) the set number of taxonomic ranks
   (b) the order of cells that have joined to form long strands or clustered arrangements
   (c) the classifications of all organisms
   (d) the evolutionary relationship between and among species (1.3) K/U
7. Which of the following is the name given to single-celled organisms that do not contain membrane bound organelles? (1.4) K/U
   (a) prokaryotes
   (b) eukaryotes
   (c) protists
   (d) none of the above
8. Which of the following groups make up Carl Woese's three domains of life? (1.4) A
   (a) plants, animals, and fungi
   (b) bacteria, archaea, and eukaryotes
   (c) prokaryotes, eukaryotes, and protists
   (d) heterotrophs, autotrophs, and microtrophs
9. In addition to the dinosaur link, evidence also suggests a connection between birds and
   (a) fish
   (b) amphibians
   (c) mammals
   (d) crocodilians (1.5) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

10. Autotrophs are able to make their own food and are therefore not dependent on any other organisms. (1.1) K/U
11. Differences in hair, skin, and eye colour are all examples of genetic diversity. (1.1) K/U
12. The physical and behavioural changes that occur in a species over time are referred to as evolutionary changes. (1.1) K/U
13. There is one correct way to classify organisms. (1.2) K/U
14. Carl Linnaeus is considered the "father" of taxonomy. (1.2) K/U
15. Today, most taxonomists use similarity as the basis for grouping organisms rather than relying on the principle of relatedness. (1.2) K/U
16. In publishing *On The Origin of Species*, Charles Darwin refuted the theory of evolution. (1.3) K/U
17. Clades can be either large or small. (1.3) K/U
18. The Linnaean classification system recognized only four kingdoms of living things. (1.4) K/U
19. Protists are by far the most diverse group of organisms. (1.4) K/U
20. Birds are the easiest group of organisms to classify. (1.5) K/U
21. Scientific understanding is advancing all the time as new evidence is discovered. (1.5) K/U

To do an online self-quiz, GO TO NELSON SCIENCE

CHAPTER 1 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. Dandelions (which reproduce asexually) must be classified based on their shared features rather than as members of a population of breeding individuals. You have just used
   (a) hybridization
   (b) genetic diversity
   (c) individual variability
   (d) morphology (1.1) K/U A
2. What are differences in hair, skin, and eye colour in humans the results of? (1.1) K/U
   (a) genetic diversity
   (b) species diversity
   (c) hybridization
   (d) the environment
3. Loss of biodiversity
   (a) threatens our food supply
   (b) eliminates sources of natural medicines
   (c) causes habitat destruction
   (d) all of the above (1.1) K/U
4. Which of the following is the highest taxonomic level of the traditional Linnaean system of classification? (1.2) K/U
   (a) species
   (b) genus
   (c) order
   (d) kingdom
5. Which of the following is true of the binomial nomenclature system? (1.2) K/U
   (a) It saw resistance and slow acceptance.
   (b) It was never fully adopted by scientists.
   (c) It assigned each species a two-word name.
   (d) all of the above
6. What is the name given to the diagram depicting the evolutionary relationships between different species or groups? (1.3) K/U
   (a) taxonomic rank of classification
   (b) great chain of being
   (c) phylogenetic tree
   (d) none of the above
7. Which of the following is true about traditional classification systems? (1.3) K/U
   (a) They group species according to evolutionary relatedness.
   (b) They are the only type of classification systems used by scientists.
   (c) They group species according to observed morphological characteristics.
   (d) They are no longer used by scientists.
8. Most prokaryotes consist of
   (a) no cells
   (b) individual cells
   (c) many cells
   (d) clustered arrangements of cells (1.4) K/U
9. Birds are difficult to categorize because they share similarities with organisms from different classes. Which two classes have taxonomists placed birds in? (1.5) K/U
   (a) mammals and reptiles
   (b) aves and reptiles
   (c) mammals and aves
   (d) aves and amphibians

Match each kingdom on the left with the domain it belongs to on the right.

10. (a) Kingdom Eubacteria (i) Domain Eubacteria
    (b) Kingdom Archaea (ii) Domain Archaea
    (c) Kingdom Protista (iii) Domain Eukaryotes
    (d) Kindgom Fungi (1.4) K/U
    (e) Kingdom Plants
    (f) Kingdom Animals

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

11. Hybridization is a very common occurrence in animals. (1.1) K/U
12. Biologists have identified and described more than 1.7 million species. (1.1) K/U
13. Taxonomy is only useful for classifying species currently living on Earth. (1.2) K/U
14. Biologists use dichotomous keys to help them identify organisms. (1.2) K/U
15. All taxonomists currently use one standard method for classifying organisms. (1.3) K/U
16. Animals are by far the most diverse kingdom of organisms. (1.4) K/U
17. Birds are closely related to dinosaurs and reptiles. (1.5) K/U

Write a short answer to each question.

18. What are heterotrophs, and what do they feed on? (1.1) K/U
19. List three features of humans that are affected by genetic diversity. (1.1) K/U

20. Past mass extinction events have been linked to large-scale disruptions in Earth's climate, caused by factors such as meteor impacts and volcanic activity. What factor is directly responsible for the current high species extinction rate? (1.1) K/U
21. List the seven main traditional taxonomic ranks of classification, in descending order. (1.2) K/U
22. Carl Linnaeus decided that, in addition to a unique, long descriptive name, each species should be assigned a simpler name. What is this naming system known as, and how many words does the system use to describe a species? (1.2) K/U
23. What is a dichotomous key? (1.2) K/U
24. In a phylogenetic tree, species are grouped into clades. What does a clade consist of? (1.3) K/U
25. Regardless of their size, clades are based on the most fundamental connection between species. What is this most fundamental connection? (1.3) K/U
26. On what factor would today's "purist" taxonomist base classifications? (1.3) K/U A
27. The Linnaean classification system recognized only two kingdoms of living things. What are those two kingdoms? (1.4) K/U
28. How many kingdoms are included in the system of classifying living things most biologists use today? (1.4) K/U
29. In 1996 Carl Woese revealed that all organisms could be classified into three fundamentally distinct groups called domains. Name the three domains. (1.4) K/U
30. Two of the three domains contain only one kingdom each. The third domain contains the other four kingdoms. Which of the three domains contains four kingdoms, and what those four kingdoms? (1.4) K/U
31. Name two key characteristics that birds share with mammals. (1.5) K/U
32. What was significant about the discovery of *Archaeopteryx* in 1861? (1.5) K/U

Understanding

33. What is hybridization? (1.1) T/I
34. Over millions of years it is not uncommon for species to experience evolutionary change. Name and describe an example of a species that has undergone evolutionary change. (1.1) T/I
35. Different species vary in their behaviours, ecological niches, and abundance. They also vary in their genetic makeup, referred to as genetic diversity. (1.1) T/I
    (a) Where do we get our genetic information from?
    (b) Choose a classmate and compare yourself to him or her. List three differences between you that are a result of genetic diversity.
36. Heterotrophs and autotrophs are very different types of organisms. (1.1) T/I
    (a) Define what makes an organism an autotroph.
    (b) List one example of an autotroph and explain how you know it is this type of organism.
37. Describe what the main difference is between taxonomists and botanists. (1.2) T/I
38. Many early classification systems were based on assumptions that were later proven invalid or misleading. The Great Chain of Being classification system was no exception to this. Identify two of the downfalls to using the Great Chain of Being classification system for species. (1.2) T/I
39. Swedish naturalist Carl Linnaeus is considered the "father" of taxonomy. Among his contributions to modern day taxonomy was the binomial nomenclature system. Describe the benefits or advantages to using this system. (1.2) T/I
40. Describe how to correctly write a binomial species name. (1.2) K/U
41. Phylogeny is the science that deals with evolutionary relationships between and among species. These relationships can be presented in a phylogenetic tree. Draw a simple phylogenetic tree that shows the evolutionary relationship between three different species. (1.3) T/I A
42. Carefully examine the phylogenetic tree in **Figure 1.** What do the lines, or branches, represent? How do you interpret kinship, or relatedness, of any two species? Describe the relationships among the species shown. (1.3) K/U T/I

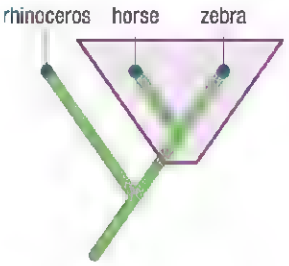


Figure 1 A phylogenetic tree

43. Clades are groupings used to help construct phylogenetic trees. (1.3) T/I
    (a) Explain how clades can be either small or very large.
    (b) Give one example each of a small clade and a very large clade.
44. Phylogenetic analysis can uncover the evolutionary relatedness of organisms. There is, however, one major challenge in using this system. (1.3) T/I
    (a) Identify what this challenge is.
    (b) How can this challenge be overcome?

45. Explain why the Kingdom Protista is such a diverse group of organisms by identifying and describing two of the organisms within this group that are very different from each other. (1.4) T/I

46. (a) Identify two characteristics that humans, sponges, insects, and birds all have in common.
    (b) Are these four groups in the same Kingdom or different Kingdoms?
    (c) Name the kingdom(s) they belong to. (1.4) T/I

47. Describe how, in 1996, Carl Woese elaborated on Carl Linnaeus's ideas and further refined the phylogenetic tree. (1.4) T/I

48. Identify the three domains of organisms as well as the kingdoms that fall under each domain. (1.4) K/U T/I

49. Fossil evidence links birds closely with a group of carnivorous dinosaurs. Describe the characteristics that link birds to this group of dinosaurs. (1.5) K/U T/I

50. Compelling evidence suggests that birds should be placed in the same taxonomic group as reptiles. Why do some taxonomists still choose to place birds in a separate class? (1.5) T/I

51. Use the phylogenetic tree in **Figure 2** to explain why the class Reptilia is not a valid taxon unless the birds are included. (1.5) T/I

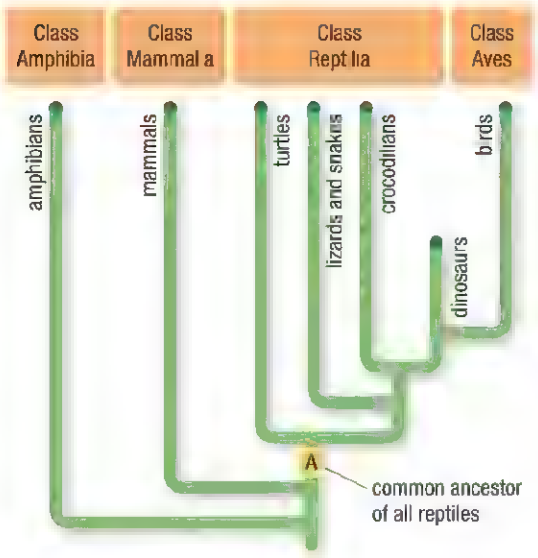


Figure 2 A phylogenetic tree according to traditional taxonomy

Analysis and Application

52. Evolutionary changes usually occur over long periods of time and often over long distances. For example, raccoons in Ontario may vary from those in South America, but raccoons within the Greater Toronto Area do not vary much. Cite examples of how species can vary over time and over space. (1.1) K/U T/I A

53. Many species living in the high Arctic are already feeling the impact of climate change, such as the caribou. Caribou rely on lichen and small plants for food. The warming climate means that lichen and small plants are being replaced with larger plants. (1.1) K/U T/I A
    (a) Explain how this is an example of structural diversity adversely affecting biodiversity.
    (b) What do you think the even longer term affects on this region could be if these changes in Arctic vegetation continue on this pattern? What might it mean for the caribou? What might it mean for other organisms in the region?

54 Ecosystems are made up of many different species and their physical environment. All these species depend on other species in some way for their own survival. (1.1) T/I A
    (a) Use examples to illustrate why species diversity and structural diversity within an ecosystem are so important.
    (b) Include an example of each type of diversity

55. Although more than 10,000 new species are discovered each year, there is serious concern among the world's leading biologists that the diversity of life is declining rapidly. (1.1) T/I A
    (a) Identify the reasons why this is occurring.
    (b) In what ways will humans be affected by a loss in biodiversity?

56. The following is a list of some Latin (Lat.) and Greek (Gr.) words and their English definitions: (1.2) K/U T/I A

- *alopekos* (Gr.): fox
- *articus* (Lat.): arctic
- *alpinus* (Lat.): mountain
- *lagos* (Lat.) or *lepus* (Gr.): rabbit
- *mephitis* (Lat.): bad odour
- *ursus* (Lat.): bear
- *pous* (Gr.): foot
- *canis* (Lat.): dog
- *aquaticus* (Lat.): found in water
- *latrans* (Lat.): a barker

Match each scientific name with the correct common name.

(a) *Ursus maritimus*	(i) arctic shrew
(b) *Sorex arcticus*	(ii) swamp rabbit
(c) *Canis latrans*	(iii) skunk
(d) *Mephitis mephitis*	(iv) coyote
(e) *Alopex lagopus*	(v) alpine chipmunk
(f) *Neotamias alpinus*	(vi) arctic fox
(g) *Sciurus arizonensis*	(vii) polar bear
(h) *Sylvilagus aquaticus*	(viii) Arizona gray squirrel

57. Analyze the work of Carl Linnaeus. Consider all that he contributed to biology and taxonomy. (1.2) K/U T/I A
    (a) Why were his contributions important?
    (b) How is taxonomy different today than it was before Linnaeus?
58. Biologists use dichotomous keys to help them identify organisms. A dichotomous key is a structure in which a large set of items is broken down into smaller subsets, ultimately leading to the smallest available classification unit. (1.2) T/I A
    (a) Brainstorm a list of eight of your favourite foods and create a dichotomous key using these eight foods.
    (b) How is your dichotomous key different from one a taxonomist might find useful? How is it the same?
59. Phylogeny is the science that deals with evolutionary relationships between and among species. These relationships can be presented in a phylogenetic tree, a branching diagram used to show the evolutionary relationships between and among species. Refer to the phylogenetic tree in **Figure 3** below to answer the following questions. (1.3) K/U T/I A
    (a) Which of the species shown are most closely related?
    (b) Hypothesize as to why you think taxonomists would consider these species to be most closely related, based on the phylogenetic tree.

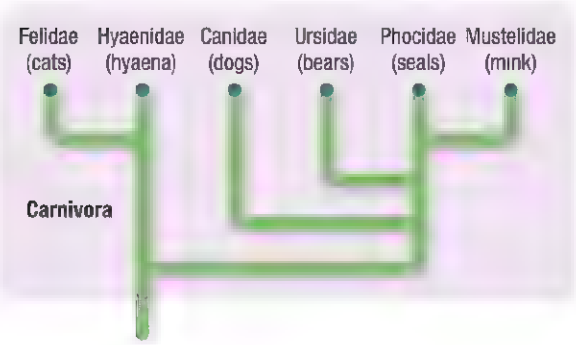


Figure 3 A phylogenetic tree for Carnivora

60. Taxonomists today choose different methods for classifying organisms. Some are "purists," basing classifications strictly on phylogenetic relationships. Others still prefer to group species by more easily recognizable features. (1.3) K/U T/I A
    (a) Compare and contrast both forms of classification, showing the strengths and weaknesses of each.
    (b) Which classification system do you prefer? Why?
61. Today, most biologists classify the more than 1.7 million known living species into six kingdoms. Choose two of the six kingdoms to compare and contrast. (1.4) K/U T/I
    (a) What are the similarities between the organisms within these two kingdoms?
    (b) What are the differences between the organisms within these two kingdoms?
62. Explain why the Kingdom Protista is by far the most diverse group of organisms. What makes this group so diverse? What types of organisms does this group consist of? (1.4) K/U T/I A
63. Analyze how the use of microscopes changed our understanding of the diversity of life and the way in which scientists classified organisms. (1.4) K/U T/I
64. In 1996, Carl Woese used a detailed analysis of living organisms to uncover some of the key relationships between the six kingdoms of life. He revealed that all organisms could be classified into three fundamentally distinct groups. (1.4) K/U T/I
    (a) Compare and contrast Woese's findings with those of his predecessors such as Linnaeus.
    (b) Were Woese's findings completely different or did he simply elaborate on existing ideas?
65. The simplified phylogenetic tree in **Figure 4** shows the key evolutionary relationships of the six kingdoms. (1.4) K/U T/I A
    (a) Discuss how such a diagram helps biologists and taxonomists.
    (b) How does the tree depict evolutionary relationships?

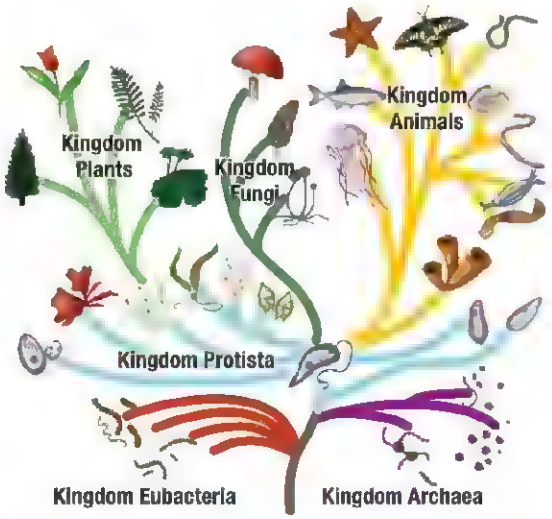


Figure 4 The six kingdoms of life

66. While birds have many unique and easily distinguished features, they are challenging to classify compared with other major groups. Why is this? (1.5) K/U T/I

67. Based on what you have learned in this chapter, what evidence supports the hypothesis that birds are descended from dinosaurs? Support your answers with phylogenetic evidence. (1.5) T/I A

68. What does it tell you about biology and taxonomy to know that systems of classification have themselves been evolving over time? Do you think there is still room to grow, expand, and better pinpoint the links between species? Support your answer. (1.5) K/U T/I C

Evaluation

69. There is no doubt that all species depend on one another. Maintaining and enhancing biodiversity is essential for the health and sustainability of ecosystems. (1.1) K/U C A
    (a) Choose a species, ecosystem, or habitat that you know is at risk today.
    (b) Recommend a plan to put in place that might help stop or reverse the decline that this species, ecosystem, or habitat is experiencing.
    (c) Present your plan in the form of a paper to a wildlife advocacy group.

70. Devise an ecosystem made up of at least six species that each depend on another in some way. Show how the species interact, and how each is able to create its own niche within the ecosystem. Be creative in your response. (1.1) K/U T/I A C

71 The best criteria for classifying organisms depend on the purpose of the classification system. Consider how the following categories of organisms might be helpful and to whom. (1.2) K/U T/I A
    (a) sharks that thrive in shallow waters
    (b) shore birds with fragile habitats

72 Botanists have been preoccupied with taxonomy for centuries. In fact, the earliest written record of plant names dates back to Ancient Greece, more than two thousand years ago. (1.2) K/U T/I A
    (a) Assess why in such distant history there might have been the need for a classification of plants.
    (b) What value might there have been so long ago in knowing the relationships between different species of plants?

73. In the past three centuries, taxonomy has in many ways come a long way and in other ways has not changed much at all. Compare and contrast the classification systems from the eighteenth century to those today. How are they the same? How are they different? (1.3) K/U T/I C

74. **Figure 5** shows the Domain Eukaryotes from Carl Woese's three domains of life. Why do you think we pay so much attention to the plants and animals when they are just two very small branches on this tree? Support your answer with facts about plants and animals and facts about the other organisms on the tree. (1.4) T/I A

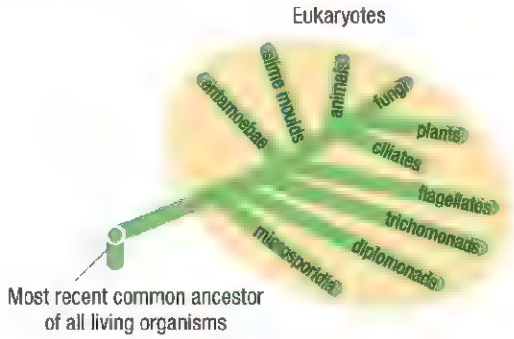


Figure 5 The three domains of life

Reflect on Your Learning

75. Based on what you have learned in this chapter, describe what our world might be like with less biodiversity. T/I C A

76. Brainstorm ways that taxonomy is useful to you in your everyday life. Include examples of classification systems that you use and are familiar with. T/I C A

77. What information in this chapter was most surprising to you? How has this information altered your understanding of the diversity of life? K/U A

78. Outline some of the significant changes in scientific understanding of both the diversity of living organisms and how they are interrelated. K/U T/I

Research

GO TO NELSON SCIENCE

79. New species are continuously being discovered. Do online research to learn about a recently discovered species. Describe the species and the location where it was found. Compare your findings with those of your classmates. T/I

80. Many species are highly dependent on one or a few other species for their survival. Conduct research to learn about the diversity of relationships between the following pairs of species. Do you think these species would be able to survive without each other? Explain. K/U T/I A
    (a) acacia ants and acacia trees
    (b) clown fish and anemones
    (c) hermit crabs and snails
    (d) cow birds and other small bird species
    (e) remoras and sharks
    (f) trillium flowers and ants
    (g) Honduran white bats and heliconia plants
81. Research marine biologists and botanists. Compare and contrast a day in the life of each. In what ways are their days very similar? In what ways are they very different? Write a paragraph about each. Be creative in your answer. K/U T/I A C
82. Bananas are generally grown in large plantations of monocultures (**Figure 6(a)**). Do online research to find answers to the following questions: T/I
    (a) How biologically diverse are bananas? How many wild species have been identified?
    (b) Which species are used for large-scale commercial production?
    (c) What is the purpose of covering the fruit with plastic bags as they grow (**Figure 6(b)**)?
    (d) How does the overall environmental impact of a banana plantation compare with that of the forest it replaced?

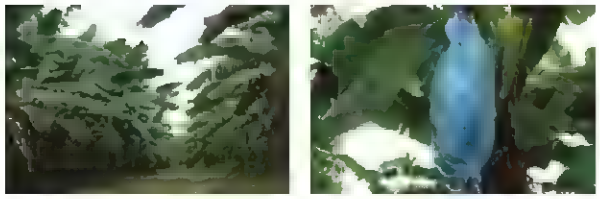


Figure 6 (a) A monocu ture banana plantation (b) A bunch of bananas covered with a plastic bag

83. The names by which we refer to animals can sometimes be quite misleading. T/I A
    (a) Go online to compare the following three groups of "worms":
        (i) earthworms
        (ii) flatworms
        (iii) roundworms
    (b) What did your findings suggest about the advantages of using scientific names rather than common names?
84. The short-tailed shrew, *Blarina brevicauda*, is venomous. Conduct research to learn how Canadian scientists are hoping to use this venom. T/I
    (a) Who first purified the venom?
    (b) What company is named after the venom?
    (c) What are the possible uses of this venom?
    (d) Outline the connection between university research and this private pharmaceutical company.
85. Clades are based on the most fundamental connection between species: their evolutionary relatedness. K/U T/I
    (a) Research and draw a clade of a family of species of your choosing, showing several of its members.
    (b) How does the use of clades help taxonomists in their classifications of organisms?
86. In September 2010 the CN Tower in Toronto was lit up with a barcode pattern as part of the official launch of the International Barcode of Life Project (iBOL). Do online research to answer the following questions about this massive scientific undertaking: T/I
    (a) How many species have already been barcoded?
    (b) How can barcoding help identify new species?
    (c) What is BOLD? How will scientists use this resource?
    (d) What types of species are being barcoded first?
87. Type the name "Rodrigo Gamez" into a computer search engine. Gather as much information as you can on this important scientist and all of his contributions to biology and taxonomy. Write a report on your findings. Present your report to your classmates. T/I C A
88. Research dichotomous keys on the Internet. Look up their numerous and varied uses. Write a report on the different types of dichotomous keys you discover. Include in your report instructions on how to create a dichotomous key. Present your report to your classmates. T/I C A
89. There are 37 members of the Felidae—the cat—family. They include lions, tigers, leopards, cheetahs, lynx, and many others. Of these, 36 are threatened—only the house cat is not. How would you feel if many of these species went extinct? Do online research to learn why members of the cat family are so threatened. T/I
90. Research horseshoe crabs on the Internet. They were once believed to be closely related to other common crabs. What evidence suggests they are actually more closely related to spiders and scorpions? Present your findings to the class. T/I A

CHAPTER 2

The Prokaryotes, Viruses, and Protists

KEY CONCEPTS

After completing this chapter you will be able to

- describe and compare the characteristics of prokaryotes, protists, and viruses
- examine important relationships between organisms, the environment, and human health
- explain how viruses cause disease
- recognize the impact that human actions can have on the survival of even the smallest organisms
- explain key steps in the evolution of eukaryotes
- classify and draw biological drawings of micro-organisms

How Important Are Microscopic Organisms?

Most living things are not visible to the unaided human eye. You are surrounded by billions of microscopic organisms. Even your own body is inhabited by countless organisms that go unnoticed. What are these organisms, and what do they do in the air, water, and soil that surround us? And what do they do *inside* us?

The cause of infectious diseases was a mystery for much of human history. Then, in the seventeenth century, the microscope was invented and the amazing world of *micro-organisms* was revealed.

Scientists now know that microscopic bacteria, viruses, and protists are the cause of most infectious diseases. Scientists also know that these simple organisms are present in abundant quantities and play key roles in ecosystems. Some of these organisms recycle nutrients, and others are important producers. Some can cause disease, while others provide substances that we can use to treat disease. Our own bodies contain bacteria that help us digest food, as well as bacteria that can make us sick. Scientists have even discovered that some of the largest organisms on Earth are actually multicellular versions of these simple microscopic life forms.

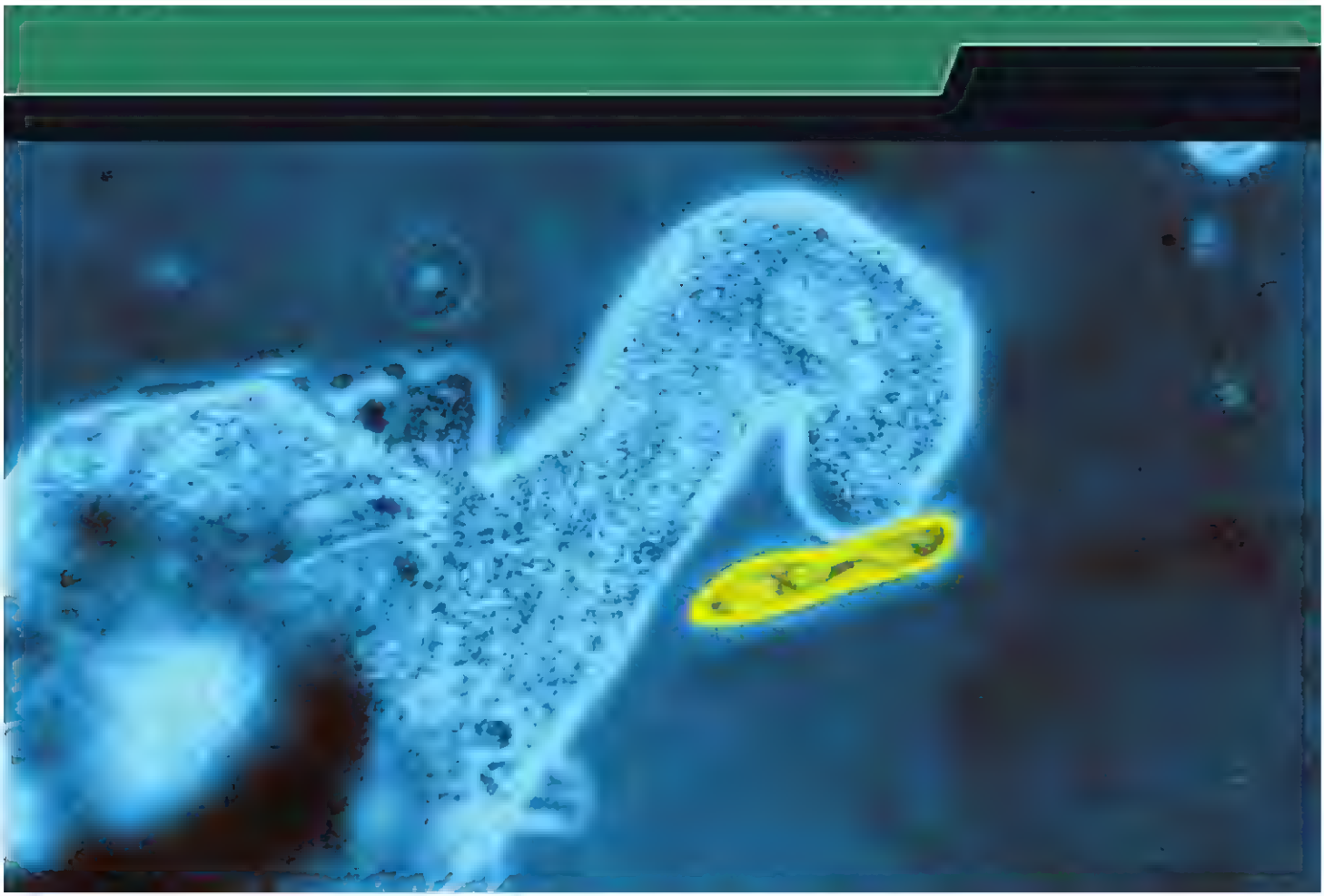
Understanding the microscopic and remarkable world of prokaryotes, viruses, and protists is extremely important. Our knowledge of the smallest organisms is helping us address some of our greatest concerns about our health and the health of our environment. This knowledge has led to dramatic improvements in medicine, including ways to prevent and treat many serious diseases. We also use our knowledge of micro-organisms to help us fight pollution and climate change.

In this chapter you will explore the great variety and value of Earth's simplest life—and life-like—forms.

STARTING POINTS

Answer the following questions using your current knowledge. You will have a chance to revisit these questions later, applying concepts and skills from the chapter.

1. How do you think microscopic organisms benefit you in your everyday life?
2. Overall, would you describe microscopic organisms as helpful or harmful?
3. In what ways do you think microscopic organisms are different from one another? In what ways do you think they are the same?
4. How do you think microscopic organisms can significantly influence an ecosystem that includes many very large organisms?



Mini Investigation

Success in Numbers

Skills: Predicting, Performing, Observing, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1

Some micro-organisms can reproduce very quickly. In this activity you will model the growth rate of a population of bacteria under ideal conditions. In your model, each bacteria cell grows and divides once each hour, so the population doubles in size each hour.

Equipment and Materials: large bucket; eyedropper; small and large graduated cylinders; water

1. Place 1 drop of water in a large bucket. This drop represents the size of the starting population. Predict how full the bucket will be after the population has doubled 10 times.
2. Create a table to record the size of the population.
3. Add 1 more drop of water to the bucket. This drop represents the doubling of the population during the first hour.
4. Add 2 more drops of water to the bucket to represent the doubling of the population during the second hour.
5. Keep doubling the population by adding drops of water to the bucket. When you reach the fourth hour, substitute 1 mL of water for 16 drops. Begin recording the population size in millilitres instead of drops. Stop when the population has doubled 10 times. Compare your prediction in Step 1 with the data from your model. Now predict how full the bucket will be after the population has doubled another 10 times. Continue doubling the population to test your prediction.

A. Did the growth rate of the model bacteria population surprise you? Explain. K/U

B. How might the ability to reproduce quickly benefit microscopic organisms? A

C. How might understanding how quickly a microscopic organism can reproduce help a physician treat a patient with an infection? A

D. Brainstorm examples in everyday life where microscopic organisms grow quickly. C A

2.1 The Prokaryotes: Eubacteria and Archaea

Organisms in Domain Eubacteria (commonly called bacteria) and Domain Archaea are prokaryotes. They are single-celled organisms, and they lack membrane-bound organelles. Prokaryotes are the smallest organisms on Earth (**Figure 1**) and some of the most important. Most prokaryote species are only 1 µm to 2 µm long—500 to 1000 of them would fit side by side across the dot of this letter "i."

LEARNING TIP

Micrometres (µm)
A micrometre also known as a micron, is indicated by the symbol µm. It is a unit of length equal to one millionth of a metre.

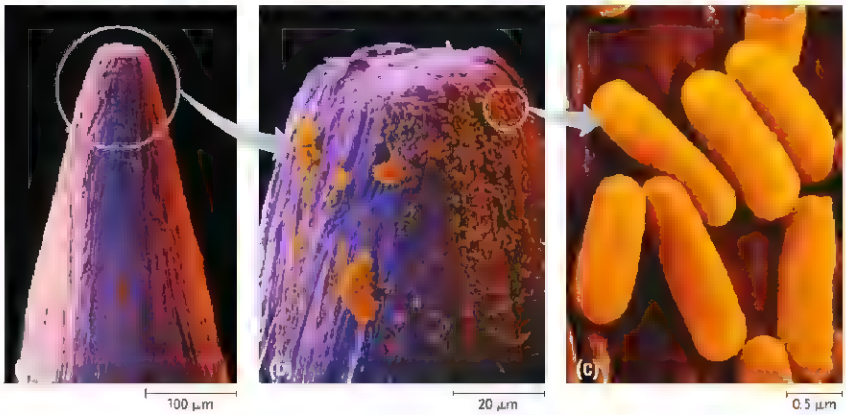


Figure 1 *Bacillus* bacteria on the point of a pin. The images are magnified (a) 70×, (b) 350×, and (c) 14 000×.

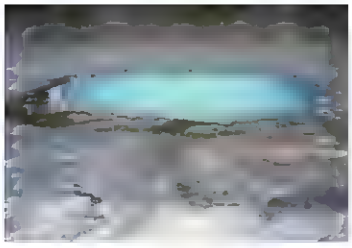


Figure 2 Many prokaryotes inhabit extreme environments. Some species live in the high temperatures found in boiling hot springs.

Despite their small size, prokaryotes are dominant forms of life that live in every imaginable habitat. They live inside and on the surface of other organisms, in water and soil, deep within Earth, in boiling hot springs (**Figure 2**), and even in ice. For example, more than 100 trillion bacteria live on and within your body. These bacteria outnumber all the other cells in your body! In fact, prokaryotes vastly outnumber all living things on Earth. Their total mass exceeds that of animals and possibly all plant life on Earth.

Everything we know so far about prokaryotes is based on a tiny fraction of the total number of species. Only about 10 000 prokaryote species have been isolated and identified, and this may represent as little as 1 % of the total number of species. Why have we identified so few species, and why are we not even sure how many prokaryotes there might be? In order to identify and study prokaryotes, scientists must first find and collect live specimens, then grow them in the laboratory. Unfortunately this is extremely difficult, partly because many prokaryotes live in remote locations and in extreme conditions.

Why Prokaryotes Are Important

Prokaryotes are extremely important organisms in many ways. Bacteria are the prokaryotic organisms most familiar to us. They are perhaps best known for their harmful effects. Bacteria are responsible for many diseases in humans and in other organisms. Infectious bacteria are called **pathogens** and are responsible for many human deaths each year. Bacterial diseases include cholera, leprosy, typhoid fever, strep throat, salmonella poisoning, and tuberculosis. Bacteria also infect livestock and crops and therefore threaten our primary food sources.

It is important to keep in mind that from the perspective of the infected organism, pathogens are harmful. However, diseases that harm one species can benefit another. For example, diseases that weaken predators benefit their prey.

pathogen a disease-causing agent, often a virus or micro-organism

UNIT TASK BOOKMARK

Is your chosen group of species threatened by pathogens? Are any other factors, such as climate change, contributing to the threat?

Although some bacteria can be harmful, others play a very positive overall role on Earth, and without them we could not survive. Bacteria, and some archaea, play key roles in ecosystems. Many are decomposers, and others are producers. These micro-organisms also recycle nutrients and are vital to biogeochemical cycles. Bacteria fix, or convert, atmospheric nitrogen into chemical compounds that can be used by plants. Photosynthetic bacteria are the major producers in marine ecosystems and are therefore major producers of atmospheric oxygen.

Bacteria are also important residents in the intestines of animals. For example, humans rely on bacteria in the large intestine to produce needed vitamins K and B12. So, although the bacteria benefit from living within the intestine, the individual also benefits from the action of the bacteria. This type of relationship between two species that are interdependent, where each benefits from the other, is known as **mutualism**.

Bacteria also have many commercial uses. They are essential in the production of foods such as cheeses, yogurt, soy sauce, and chocolate (**Figure 3**)! Bacteria also produce substances known as **antibiotics**, which can destroy or inhibit the growth of other micro-organisms. Genetic engineers have even modified some bacteria to produce medically valuable compounds, including insulin and human growth hormone.

Archaea are a group of prokaryotes that were discovered only about 40 years ago. Scientists do not know as much about archaea as they do about bacteria, but we do know that these species play key roles in many ecosystems. Archaea live in some of the most extreme environments on Earth, such as hot springs, Arctic ice floes, and highly acidic waters. They also live in the intestines of some animals, including humans. No species from Domain Archaea are known to cause disease.

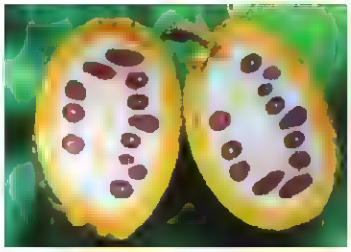


Figure 3 Yeast and bacteria are used in the process that produces chocolate from cacao (*Theobroma cacao*) beans.

mutualism a relationship between two species that live in very close association with each other, whereby each benefits from the association

antibiotic a substance that can kill or weaken micro-organisms; natural antibiotics are produced by bacteria or fungi, whereas synthetic antibiotics are manufactured

CAREER LINK

Cheese Maker

To learn more about careers in the cheese-making industry,

GO TO NELSON SCIENCE

The Domain Eubacteria

Fossil evidence shows that prokaryotes have lived on Earth for more than 3.5 billion years. Although fossils cannot provide information about how Eubacteria evolved, genetic studies suggest that species in this domain diversified early.

Classification and Phylogeny

The Domain Eubacteria has more than 12 separate evolutionary branches, or groups. **Figure 4** shows six particularly important groups of bacteria.

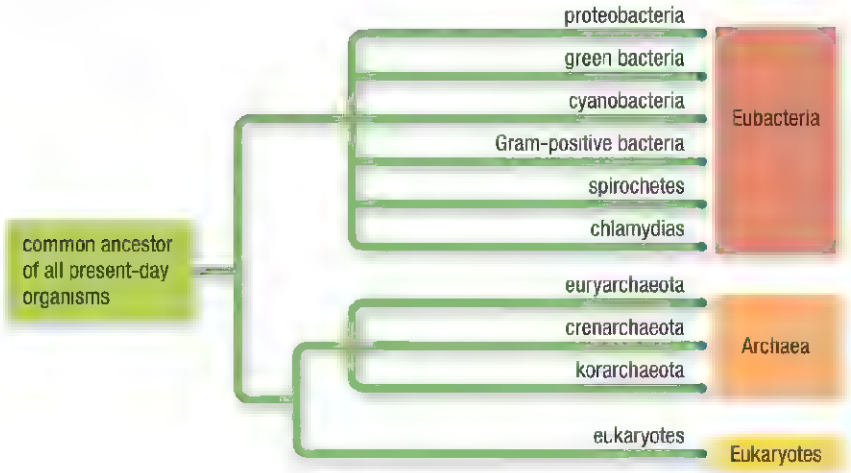


Figure 4 This phylogenetic tree shows the relationships among the three domains of life: Eubacteria, Archaea, and Eukaryotes. For simplicity, only the six major groups of bacteria are shown here.

These six groups of bacteria are extremely diverse. They vary dramatically in how they obtain energy and nutrients, in their ecological roles, and in their importance to humans.

Table 1 lists the key features of each group of bacteria. Three of these major groups are photosynthetic. Proteobacteria and green bacteria, however, use a process that is very different from photosynthesis in plants. They do not use water or release oxygen, and they use different forms of chlorophyll.

Table 1 Key Features of the Six Major Groups of Bacteria

Group	Key features
proteobacteria (purple bacteria)	• Some are photosynthetic but use a form of photosynthesis that differs from that of plants. • Ancient forms of these bacteria were the likely ancestors of eukaryotic mitochondria. • Some are nitrogen fixing. • They are responsible for many diseases, including bubonic plague, gonorrhea, dysentery, and some ulcers.
green bacteria	• They use a form of photosynthesis that differs from that of plants. • They are usually found in salt-water environments or hot springs.
cyanobacteria (blue-green algae)	• They use a form of photosynthesis similar to plants and other eukaryotes • Ancient forms of these bacteria were the likely ancestors of eukaryotic chloroplasts. • They play major roles as producers and nitrogen fixers in aquatic ecosystems. • They form symbiotic relationships with fungi.
Gram-positive bacteria	• They cause many diseases, including anthrax, strep throat, bacterial pneumonia, and meningitis. • They are used in food production (for example, lactobacillus is used in yogurt and probiotic products). • Some have lost their cell wall. • One type—mycoplasmas—are the smallest known cells (0.1 µm to 0.2 µm).
spirochetes	• Their spiral-shaped flagellum is embedded in their cytoplasm. • They move with a corkscrew motion. • They cause syphilis. • Symbiotic spirochetes in termite intestines digest wood fibre.
chlamydias	• All are parasites that live within other cells. • They cause chlamydia, one of the most common sexually transmitted infections. • They cause trachoma, the leading cause of blindness in humans.

Characteristics

Images of bacteria taken with a standard electron microscope typically show little more than a cell wall and a plasma membrane surrounding cytoplasm (**Figure 5**). However, these prokaryotic cells are relatively complex. A bacterium's chromosome is a single loop of DNA (deoxyribonucleic acid) that is found in a region called the nucleoid. Ribosomes, which are used in protein synthesis, are scattered throughout the cytoplasm. Bacteria often have one or more flagella for movement and small hair-like structures called pili (singular: pilus). The pili are made of stiff proteins and help the cell attach to other cells or surfaces. **Figure 6** shows the structure of a typical bacteria cell.

Figure 5 Bacterial cells do not have membrane-bound organelles.

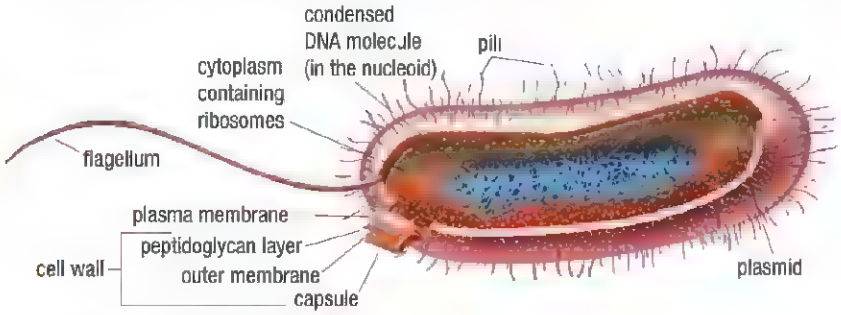


Figure 6 A representative bacterial cell

In addition to a single chromosome, many bacteria have one or more plasmids in their cytoplasm. A **plasmid** is a small loop of DNA that usually carries a small number of genes. The genes are not essential for cellular functions but often provide some advantage to the cell. For example, genes that give bacteria resistance to antibiotics are often found on plasmids.

plasmid a small loop of DNA often found in prokaryotic cells; usually contains a small number of genes

Bacteria have complex cell walls composed primarily of peptidoglycan, a large molecule that forms long chains. These chains become cross linked, making the cell wall strong and rigid. Some bacteria are also surrounded by a sticky **capsule**. The capsule reduces water loss, resists high temperatures, and helps keep out antibiotics and viruses.

capsule an outer layer on some bacteria; provides some protection for the cell

Bacteria cells vary considerably in shape. Three common shapes are **coccus** (plural: cocci), or round; **bacillus** (plural: bacilli), or rod shaped; and **spirillum** (plural: spirilli), or spiral (**Figure 7(a)** to **(c)**). Bacteria cells often occur in particular arrangements, such as pairs, clumps, or strings. The prefixes *diplo* , *staphylo* , and *strepto* are used to describe these arrangements (**Figure 7(d)**). Many species names are based on these easily recognizable characteristics. For example, the species of bacteria responsible for strep throat is *Streptococcus pyogenes*.

coccus a round bacterial cell

bacillus a rod-shaped bacterial cell

spirillum a spiral or corkscrew-shaped bacterial cell

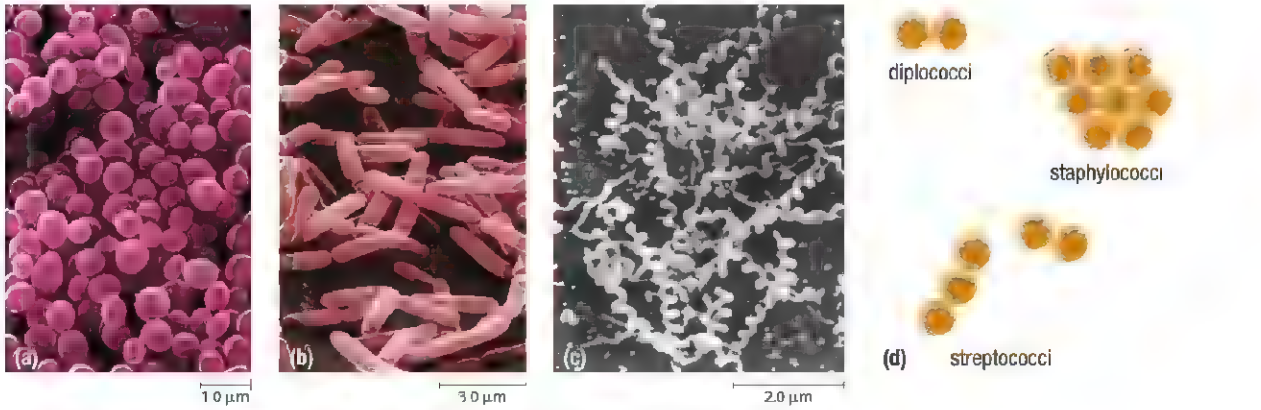


Figure 7 Bacteria cells have three common shapes: (a) cocci, (b) bacilli, and (c) spirilla. (d) They often occur in pairs (diplo), clumps (staphylo), or strings (strepto).

METABOLISM

Bacteria are extremely diverse in the ways they get nutrients and energy from their surroundings. Autotrophic bacteria make their own food. They assemble complex carbon molecules from simple **inorganic chemicals**—substances such as carbon dioxide, water, and minerals that are part of the abiotic environment. Heterotrophic bacteria get their nutrients from carbon containing **organic chemicals** found in other living organisms or their remains.

inorganic chemical a chemical that has an abiotic origin; some simple substances that are produced by organisms are also classified as inorganic

organic chemical in biology, any chemical that contains carbon and is produced by living things; carbon dioxide is an exception—it is produced during respiration but is classified as inorganic

The two primary sources of energy for living things are sunlight and chemical energy. We are most familiar with the chemical energy contained in organic chemicals such as sugars, fats, and proteins. Many bacteria can also get energy from inorganic chemicals such as hydrogen, sulfur, and iron compounds.

All animals and plants are **obligate aerobes**: they need oxygen, obtained through the process of respiration, in order to get energy from food. Some bacteria are obligate aerobes, and others are **facultative aerobes**. These bacteria perform aerobic respiration in the presence of oxygen and anaerobic respiration, or anaerobic **fermentation**, when oxygen is absent. Still other bacteria are **obligate anaerobes**: they cannot live in environments where oxygen is present.

obligate aerobe an organism that cannot survive without oxygen

facultative aerobe an organism that can live with or without oxygen

fermentation an anaerobic process that releases chemical energy from food

obligate anaerobe an organism that cannot survive in the presence of oxygen

REPRODUCTION

Prokaryotes normally reproduce asexually. In this process, a parent cell divides by **binary fission**, producing two daughter cells. Each daughter cell receives an exact copy of the genetic material from the parent cell—its chromosome and plasmids. Sometimes mistakes are made when the genetic material is copied.

binary fission the division of one parent cell into two genetically identical daughter cells; a form of asexual reproduction

Copying errors result in mutations, or changes in the genetic makeup of the cell. Bacteria reproduce very quickly, so they mutate more often than organisms that reproduce more slowly. A bacterial gene mutates roughly 1000 times as often as a eukaryotic gene. These mutations increase the genetic diversity in populations of bacteria (**Figure 8(a)**).

conjugation a form of sexual reproduction in which two cells join to exchange genetic information

transformation a process in which a bacterial cell takes in and uses pieces of DNA from its environment

horizontal gene transfer any process in which one species gets DNA from a different species; also called "lateral gene transfer"

Bacteria also increase their genetic diversity by gaining new DNA. This may happen when a bacterium is infected by a virus or through conjugation and transformation. In **conjugation**, one bacterial cell passes a copy of a plasmid to a nearby cell through a hollow pilus (**Figure 8(b)**). This can benefit the recipient cell if the plasmid provides beneficial genes. Conjugation is considered a form of sexual reproduction, because two different cells are sharing genetic information. **Transformation** occurs when a cell picks up a loose fragment of DNA from its surroundings and uses it. These DNA fragments may have been released into the environment when other cells died. If the new DNA came from a different species, the process is called **horizontal gene transfer**.

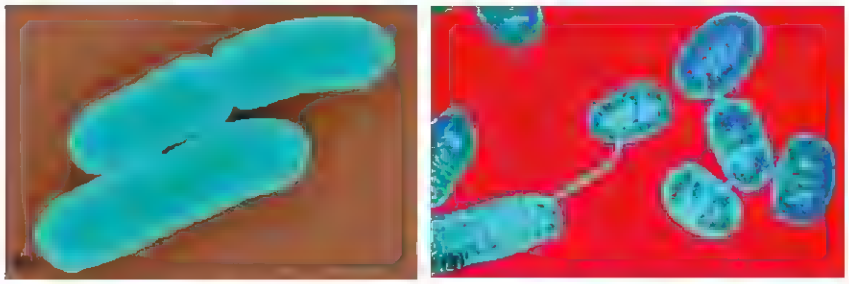


Figure 8 (a) The *E. coli* (*Escherichia coli*) cell on the top is dividing by binary fission. (b) Pairs of bacteria are joined by a pilus and are undergoing conjugation. One cell is transferring a copy of a plasmid to another cell.

endospore a dormant structure that forms inside certain bacteria in response to stress; protects the cell's chromosome from damage

Figure 9 Cyanobacteria, or blue-green algae, create an "algal bloom."

As you observed in the mini investigation at the beginning of this chapter, organisms that can double their population size in only 1 h can produce millions of individuals in a matter of hours. This fast reproduction can have dramatic ecological consequences, such as "algal blooms" in aquatic ecosystems (**Figure 9**). Algal blooms can reduce the oxygen content of water bodies and threaten other organisms, including fish.

Some bacteria have a unique strategy for surviving unfavourable conditions: they produce endospores. An **endospore** is a highly resistant structure that forms around the chromosome when the cell is under stress. Endospores can withstand extreme conditions and remain dormant until conditions improve, often for many years. Living bacterial endospores that are thousands of years old have been recovered from Egyptian mummies!

Research This

Biofilms

Skills: Researching, Analyzing, Evaluating

SKILLS HANDBOOK A2.1, A5.1

Under certain conditions, some bacteria form large colonies that stick together and to surfaces, forming biofilms. Dental plaque is a familiar example of a biofilm. In this activity you will research the characteristics and roles of biofilms.

1. Use the Internet and other resources to find out why some bacteria form biofilms.
2. Research why forming these colonies is advantageous to bacteria.
3. Research why biofilms are of particular interest to humans.

A. How and why do biofilms form?

B. What are some ecological roles and benefits of biofilms?

C. What are examples of biofilms that are harmful or damaging to property?

D. Why are biofilms of medical interest?

GO TO NELSON SCIENCE

Bacterial Diseases

Bacteria are responsible for many diseases ranging in severity from minor ear infections, which affect individuals, to the bubonic plague wiped out entire populations. **Table 2** lists a few bacterial diseases and examples of species that cause them.

Some infectious bacteria cause disease by producing and releasing toxins. For example, botulism food poisoning is caused by the toxin released by the bacterium *Clostridium botulinum*, which grows in poorly preserved foods. The toxin, botulin, is one of the most poisonous substances known. Botulin causes muscle paralysis that can be fatal if the muscles that control breathing are affected.

Other bacteria contain toxic compounds that are not released unless the cell dies. These toxins have different effects depending on the bacterial species and site of infection. One example of this type of bacteria is the *E. coli* strain O157:H7. This strain causes severe food poisoning and was responsible for the water contamination tragedy in Walkerton, Ontario, in 2000. Unlike other *E. coli*, this deadly strain has an additional piece of DNA with instructions for making the toxin. Evidence strongly suggests that this is a case of horizontal gene transfer. The strain was created when DNA was transferred to *E. coli* from the bacteria *Shigella dysenteriae*, the cause of dysentery. Antibiotics are the most successful and widely used treatment of bacterial infections. With *E. coli* O157:H7, however, the deadly toxin is released when the cell dies. A dose of antibiotics can kill many of the bacteria at once, causing a dangerous amount of the toxin to be released.

Table 2 Human Bacterial Diseases

Disease	Bacteria species
cholera	*Vibrio cholerae*
diphtheria	*Corynebacterium diphtheriae*
Lyme disease	*Borrelia burgdorferi*
pertussis	*Bordetella pertussis*
Rocky Mountain spotted fever	*Rickettsia rickettsii*
scarlet fever	*Streptococcus pyogenes*
tetanus	*Clostridium tetani*

Antibiotics and Antibiotic Resistance

Prokaryotes and fungi are often in direct competition with each other for food and resources, and they produce antibiotic substances as a form of chemical warfare. Imagine a piece of fruit that has just fallen from a tree and come in contact with fungi and bacteria on the ground. Both types of microbes would benefit from the nutrients in the fruit. By producing and releasing an antibiotic into the surroundings, one of the microbes may be able to kill the other and get the fruit.

Antibiotics are immensely valuable to humans (**Figure 10**). By mass producing a wide variety of antibiotics, we can often kill bacteria where they are unwanted. Unfortunately, though antibiotics have saved many millions of lives, they may not be so effective in the future. The overuse of antibiotics can cause bacteria to adapt and become resistant, so that the antibiotics are no longer effective (**Figure 11**).

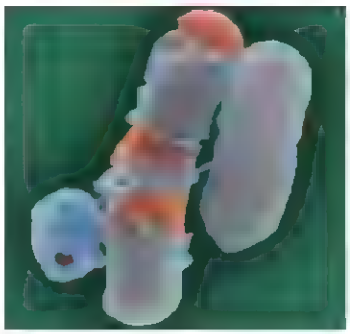


Figure 10 Penicillin killed the bacterium on the left by weakening its cell wall.

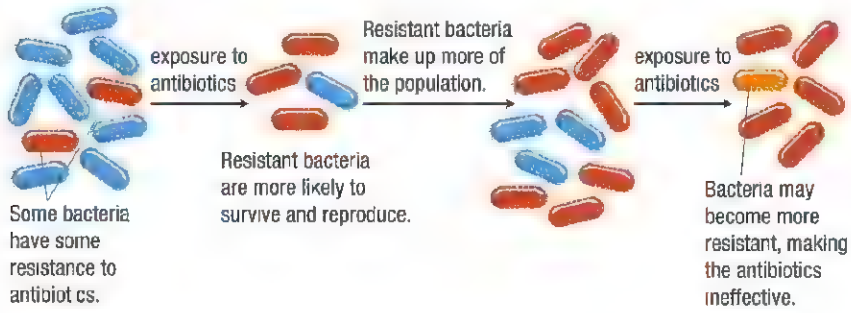


Figure 11 The process by which many bacteria develop antibiotic resistance

The Domain Archaea

Archaea are fascinating organisms, although little is known about them. These tiny prokaryotes were originally thought of as unusual types of true bacteria. They are now known to be unlike any other living thing. Their cell membranes and walls have a unique chemical makeup, and most lack peptidoglycan. Archaea also have genetic information that distinguishes them from bacteria and eukaryotes.

Figure 12 The sulfur-rich water of Emerald Hole in Yellowstone National Park has very high temperatures. Archaea can use foul smelling H_2S as a food source in this environment.

One characteristic of archaea is that many inhabit extreme environments (**Figure 12**). Some can even survive being boiled in strong detergents! Their cell membranes and cell walls are much more resistant to physical and chemical disruptions than those of other organisms.

There are three branches in Domain Archaea (see Figure 4, page 47). **Table 3** describes some examples of archaea from the group Euryarchaeota and highlights the diversity of organisms in this domain.

Table 3 Representative Archaea from the Group Euryarchaeota

Euryarchaeota subgroup	Key features

methanogens	• They live in low-oxygen environments, including
	  • sediments of swamps, lakes, marshes, and sewage lagoons
	  • digestive tracts of some mammals (including humans) and some insects
	• They generate energy by converting chemical compounds into methane gas, which is released into the atmosphere.

halophiles	• They are salt-loving organisms that can live in highly saline environments including the Dead Sea and foods preserved by salting. • Most are aerobic and get energy from organic food molecules. • Some use light as a secondary energy source.
extreme thermophiles	• They live in extremely hot environments including hot springs and hydrothermal vents on the ocean floor. • Their optimal temperature range for growth is 70 °C to 95 °C.
psychrophiles	• They are cold-loving organisms found mostly in the Antarctic and Arctic oceans, and cold ocean depths. • Their optimal temperature range for growth is −10 °C to −20 °C.

Research This

Prokaryotes and Environmental Change

Skills: Researching, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1, A5.1

Organisms as small as prokaryotes can be influenced by environmental changes. For example, some bacterial diseases may be able to spread more effectively in warmer climates. Prokaryotes might also be useful in combating environmental change and damage. For example, cyanobacteria might be used to mass-produce a "green" source of fuel. In this activity you will work with a partner to research prokaryotes and environmental change.

1. Work with a partner. Decide who will research a possible effect of environmental change on a prokaryote and who will research a possible use of prokaryotes to protect the environment.
2. Conduct some initial research to find one or two examples that interest you. Check your choices with your teacher before continuing your research.
3. If you have chosen an effect of environmental change, conduct research about the following topics:
   (i) the nature and cause of the environmental change
   (ii) the ways in which the environmental change is affecting the organism
   (iii) the likely consequences of the effects on the organism, including how other species may be affected
4. If you have chosen to research a beneficial use of a prokaryote, conduct research about the following topics:
   (i) the characteristics of the prokaryote
   (ii) the benefits that the prokaryote provides or could provide
   (iii) the current status of technology

A. Share your summarized findings with your partner. A2.1 A5.1

B. Share your findings with the class. Discuss the overall relationship between environmental change and prokaryotes. A2.1 A5.1

GO TO NELSON SCIENCE

2.1 Summary

- Bacteria are extremely abundant and play keys roles in ecosystems as producers, decomposers, and pathogens.
- Bacteria are used in the production of some types of antibiotics and many different foods.
- Bacteria are characterized by the presence of peptidoglycan in their cell walls and have diverse metabolic processes.
- Bacteria reproduce asexually by binary fission and increase their genetic diversity by conjugation and transformation.
- The ability of bacteria to develop antibiotic resistance is a serious concern.
- Archaea are an important but not well understood group of prokaryotes.
- Archaea are found in a variety of habitats including many extreme environments and the intestines of mammals.
- Archaea have unique cell membranes, cell walls, and genetic information.

Investigation 2.1.1

Observing Bacteria (page 68)
Now that you have read about the different types of bacteria, you can complete Investigation 2.1.1.

In this observational study you will observe and identify basic types of bacteria and document your findings with biological drawings.

2.1 Questions

1. List three ways in which prokaryotes are important to humans and the environment. K/U
2. Which major groups of eubacteria perform photosynthesis? Which group uses a form of photosynthesis most similar to plants? K/U
3. Describe and state the function of each of the following: K/U
   (a) nucleoid
   (b) pili
   (c) plasmid
   (d) peptidoglycan
   (e) capsule
   (f) endospore
4. Create labelled sketches of the three common shapes of bacterial cells. K/U
5. Distinguish between the following terms: K/U
   (a) inorganic and organic chemicals
   (b) obligate and facultative aerobes
   (c) conjugation and transformation
6. Conduct research to determine how the botulin toxin, released by *Clostridium botulinum*, is used in the cosmetics industry. What are the benefits and risks of this use? T/I A
7. Explain the role horizontal gene transfer is thought to have played in making the *E. coli* strain 0157:H7 so dangerous. K/U
8. What is the benefit to one kind of bacteria of producing antibiotics that kill other types of bacteria? K/U
9. (a) Describe the process by which many bacteria have developed resistance to antibiotics.
   (b) How has their ability to reproduce rapidly influenced this process? K/U T/I A
10. Describe two examples of symbiosis involving bacteria. K/U
11. Many genetic technologies rely on the ability to make copies of DNA molecules in the laboratory. This involves using chemicals that operate at high temperatures without being altered or destroyed. One of these chemicals is produced by the bacterium *Thermus thermophilus*. T/I A
    (a) Do you predict this bacterium to live in cold, moderate, or hot environments?
    (b) Conduct research to check your prediction. Were you correct? Where are these bacteria found in nature?
12. Describe three extreme environments that are inhabited by archaea. A
13. Although bacteria are typically unicellular, one group, the Myxobacteria, or "slime bacteria," form colonies containing millions of cells (**Figure 13**). Conduct research to determine how these bacteria benefit from forming such large associations. T/I

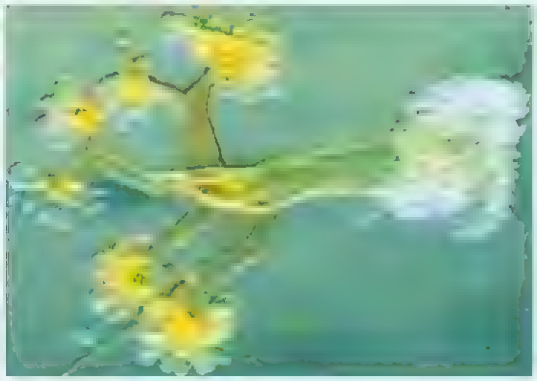


Figure 13 Colonies of Myxobacteria can contain millions of cells.

14. Imagine that you overheard someone say, "Bacteria cause disease. It would be good if we could eliminate all bacteria on Earth." Would you agree with this statement? Explain your reasoning. C
15. Certain species of bacteria are the only organisms known to be able to feed on crude oil. These bacteria play an important role in cleaning up major oil spills. Use the Internet and other sources to find out more about these bacteria. How are these species used? How do they clean up oil spills? Do they occur naturally, or are they applied to the spill by clean up crews? T/I A

GO TO NELSON SCIENCE

2.2 Viruses, Viroids, and Prions

Figure 1 Human influenza viruses cause seasonal flu. It would take 10 million viruses placed side by side to cover a distance of 1 mm.

Each fall millions of Canadians line up for an annual flu shot. The flu shot is a vaccine designed to help protect you from the influenza virus and prevent you from getting the seasonal flu (**Figure 1**).

In this section you will explore the biology of viruses and other infectious particles. You will examine their role in causing disease as well as how they can be used to treat or prevent disease.

Viruses

Viruses are small, non-living particles. A virus particle consists of genetic material surrounded by a capsule made of protein, called a **capsid**. Viruses have no cytoplasm, and many are less than 0.1 µm in diameter—hundreds of thousands of viruses could easily fit inside a typical human cell. Viruses cannot grow or reproduce on their own and do not produce or use energy. They do not create waste. You can think of them as packages of genetic instructions that can enter and take control of cells. Their genetic material is a piece of DNA or **RNA (ribonucleic acid)**. Like DNA, RNA can carry information that provides instructions for synthesizing protein molecules.

All viruses are infectious—they are passed from cell to cell and from organism to organism. After a virus enters a host cell, the viral DNA (or RNA) may begin to take control of the cell. The cell eventually makes copies of the virus.

virus a small infectious particle containing genetic material in the form of DNA or RNA within a protein capsule

capsid a protein coat that surrounds the DNA or RNA of a virus

RNA (ribonucleic acid) a nucleic acid found in all cells and some viruses; usually carries genetic information that provides instructions for synthesizing protein

Why Viruses Are Important

Viruses are responsible for many human diseases. Some viral diseases, such as the common cold and chicken pox, produce relatively mild symptoms. Others, such as AIDS, cholera, and rabies, are much more serious and can be deadly. Viral diseases are significant not only because they affect individuals, but also because of their ability to spread. Some, such as the influenza virus, are transmitted easily from person to person and can infect millions of people in a relatively short time. A large, rapidly spreading outbreak of disease in a particular region is called an **epidemic**. When an epidemic spreads on a global scale, it is called a **pandemic**. **Table 1** lists some significant viruses and the diseases they cause in humans.

epidemic a large-scale outbreak of disease; usually confined to a limited geographic region

pandemic an epidemic that occurs over a widespread geographic area, often globally

A small number of viruses play a role in certain cancers. All cancers involve uncontrolled cell division caused by mutations in the cells' DNA. When viruses infect host cells, they sometimes create changes in the host's DNA that can lead to cancer. The hepatitis C virus, for example, has been shown to be a major contributor to liver cancer.

Viruses cause diseases in wild and domestic animals as well as in humans. Plant viruses destroy millions of tonnes of crops every year, especially cereals, potatoes, sugar beets, and sugar cane.

Although some viruses can be harmful, they are important in ecosystems. By causing disease, they control the populations of other organisms. Viruses are also extremely abundant. A single millilitre of ocean water can contain millions of viruses.

Table 1 Disease-Causing Viruses

DNA viruses	Disease
hepadnavirus	hepatitis B
herpesvirus	cold sores, genital herpes, chicken pox
adenovirus	respiratory infections, tumours
RNA viruses	**Disease**
paramyxovirus	measles, mumps, pneumonia, polio, common cold
retrovirus	HIV/AIDS
rhabdovirus	rabies

Classification and Phylogeny

Viruses challenge the basic categories of living and non-living. They are classified as non-living because they do not have the key characteristics of living cells. However, viruses do share one important trait with living things: they reproduce. Unlike other living things, however, viruses cannot reproduce without a host cell. The way viruses reproduce makes them very interesting to biologists.

Viruses are classified into orders, families, genera, and species. They are classified based on a variety of features including size, shape, and type of genetic material. About 4000 virus species have been classified, but scientists believe that there may be millions.

Most viruses can infect only a single host species or a few closely related hosts. A species of virus might infect only one organ system, or a single tissue or cell type in its host. For example, human immunodeficiency virus (HIV) infects only certain immune system cells. However, some viruses can infect many species. For example, the rabies virus can likely infect all species of mammals and birds. Of the roughly 80 known virus families, 21 include viruses that cause disease in humans.

Viruses that infect bacterial cells are called **bacteriophages**, or phages. Most other types of viruses enter the host cell, but phages do not. Instead, they inject their DNA into the bacterium, and their protein capsule remains outside the cell (**Figure 2**). Phages have been the subject of intense research. Much of our early understanding about the structure and function of viruses came from this research.

bacteriophage a virus that infects bacteria

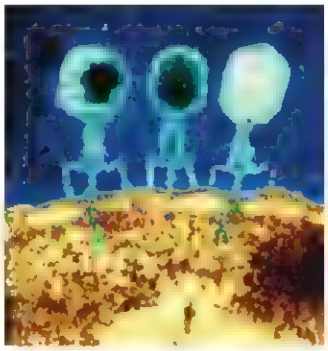


Figure 2 Three bacteriophages attach to the outer surface of a bacterium. You can see the strands of DNA that the phages are injecting into the cell.

The Origin of Viruses

Several different hypotheses have been proposed to explain the origin of viruses. One possibility is that viruses originated as small infectious cells that over time lost their cytoplasm and their ability to reproduce outside a living cell. Some biologists suspect that viruses originated as "escaped" fragments of DNA or RNA molecules that once formed part of living cells. A recent hypothesis suggests that viruses are ancient, and that virus-like particles existed even before the first cells.

Characteristics

Viruses vary in structure, but they all consist of an RNA or DNA molecule surrounded by a capsid. Some common virus shapes are shown in **Figure 3**. In addition to the capsid, some viruses are surrounded by an envelope. The envelope is created when a virus leaves a host cell and part of the host cell membrane wraps around the virus (**Figure 4**).

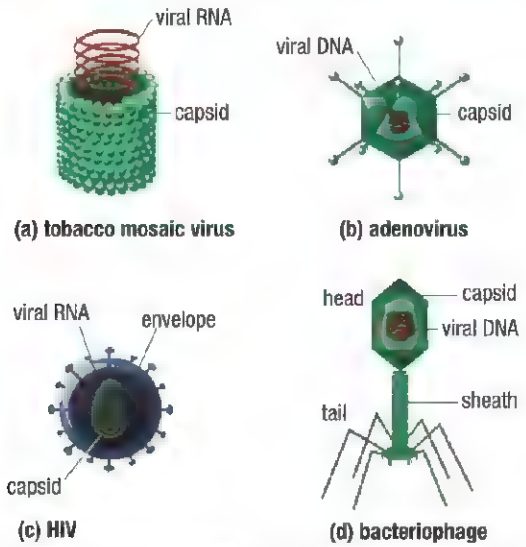


Figure 3 Viruses consist of a molecule of RNA or DNA surrounded by a capsid. (a) and (b) The capsid takes various geometric shapes. (c) Some viruses, such as HIV, also have an envelope made from the membrane of a host cell. (d) Phages have a complex head and tail structure.

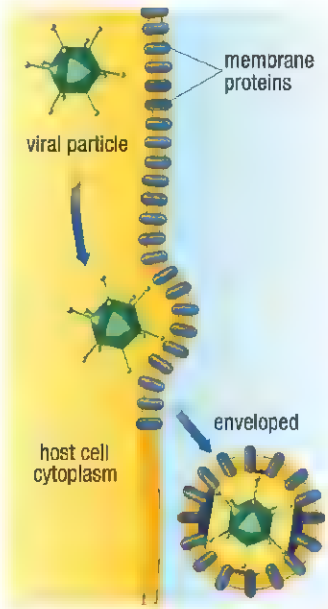


Figure 4 When some viruses leave their host cell, a membrane envelope forms around them.

Infectious Cycles

Viruses do not carry out life functions like living cells do. They become active only when their genetic material has entered and taken control of a living cell. The process by which a virus infects a host cell, replicates, and destroys the host cell is called an infectious cycle. **Figure 5** shows two common infectious cycles using the *lambda* phage as an example.

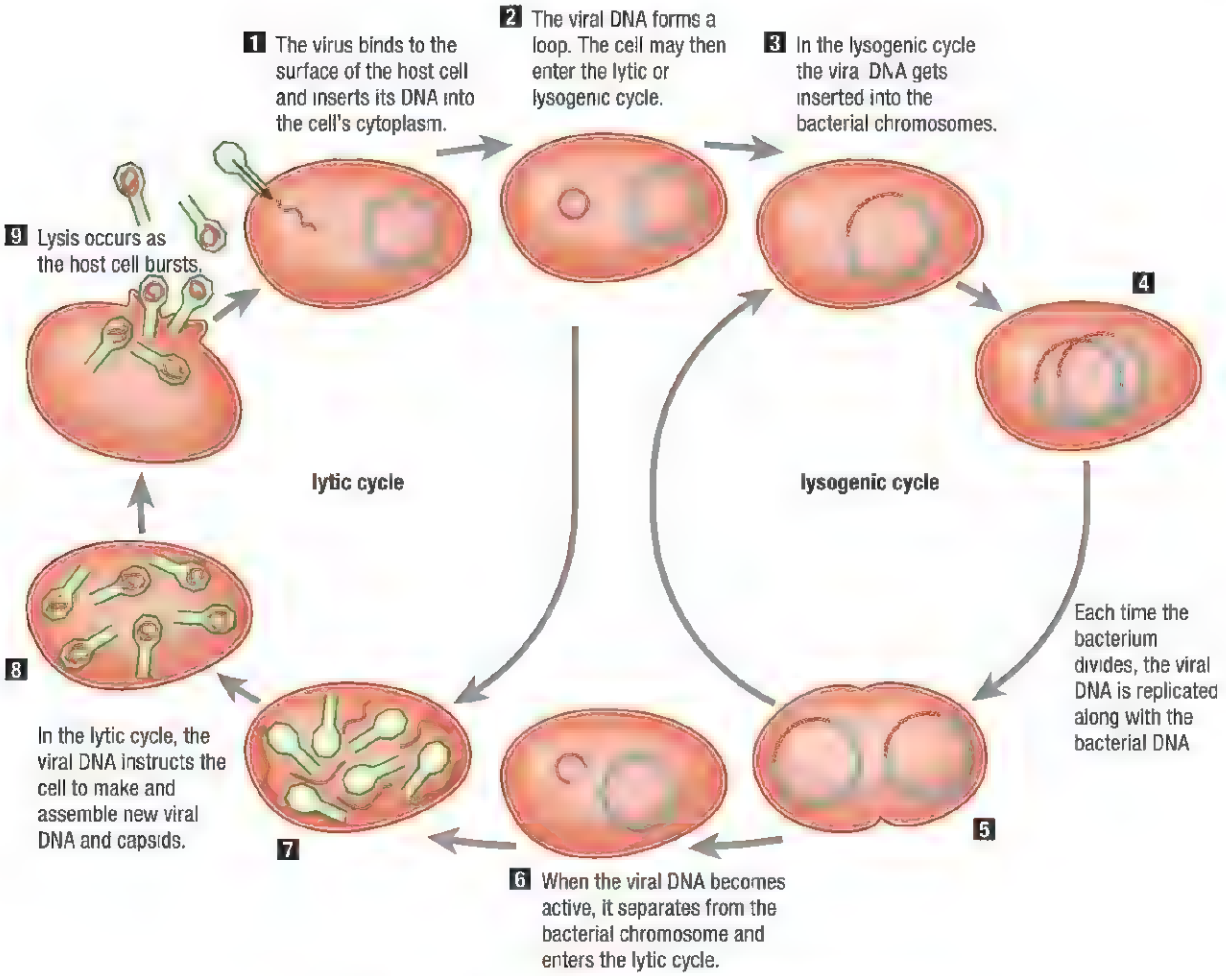


Figure 5 Phage infections can include both lytic and lysogenic cycles.

lysis the rupturing of a cell, can occur when newly made v ruses are releaseo from a host cell

lysogeny a state of dormancy in which viral DNA may remain within a host cell's chromosome for many cell cycle generations

transduction a type of gene transfer in which a virus transfers DNA from one bacterium to another

In the lytic cycle, when assembly is complete, **lysis** occurs as the host cell ruptures, or bursts, releasing about 100 to 200 new viruses into the host cell's surroundings. The host cell is then destroyed. This entire lytic cycle can take less than one hour.

In the lysogenic cycle, the viral DNA can stay in a dormant state, called **lysogeny**, for many years. The bacterium continues to grow and divide normally, but each time it divides it makes a copy of the virus DNA that was inserted within its own chromosome. When triggered by a change within the cell's environment, the viral DNA becomes active, separates from the bacterial chromosome, and enters the lytic cycle.

On rare occasions, when the viral DNA separates from the bacterial chromosome (Step 6 in Figure 5), a small piece of the bacterial DNA may separate from the chromosome and become incorporated into the viral DNA (this process is not illustrated in Figure 5). When this happens, the newly released viruses carry this piece of bacterial DNA and may insert it into different bacteria when they infect other cells. This is a form of gene transfer called **transduction**.

The infectious cycles of animal viruses follow a pattern similar to that of bacteriophages, except that the virus's capsid enters the cell along with the viral DNA. Some viruses do not cause lysis. Some animal viruses enter a dormant phase, similar to the lysogenic cycle for bacteriophages, in which the viral DNA is incorporated into the cell's chromosomes.

Sometimes the whole virus stays in the cell's cytoplasm in a dormant state. For example, the herpes viruses that infect humans remain dormant in the cytoplasm of some body cells for the person's entire life. At times, particularly during periods of stress, the virus becomes active in some cells. The viruses are replicated and destroy the cells as they are released. When this occurs in large numbers of cells, noticeable ulcers, or cold sores, form. The viruses then infect other cells and may once again go dormant. In this way, the person stays permanently infected with the virus.

Viruses are spread, or transmitted, in many ways. Some spread through the air or by direct physical contact with an infected individual. Others are spread by biting insects or enter the body through injuries. **Table 2** lists some viruses and the ways they are transmitted.

Table 2 Viral Transmission

Disease	Method of transmission
rabies	bite by infected mammal
HIV/AIDS	exchange of body fluids
influenza, common cold, chicken pox	airborne and by contact
measles, mumps	direct contact

Vaccinations and Human Health

Vaccines are mixtures that contain weakened forms or parts of a dangerous virus. When these altered viruses are injected into an individual's body, they trigger a response by the immune system without causing an infection. This exposure creates a form of chemical "memory" that allows the immune system to react quickly if the individual ever comes in contact with the real virus. Vaccination programs have dramatically reduced human suffering and saved countless lives. In countries with modern healthcare systems, many serious diseases have been nearly eliminated. Smallpox was once a dreaded disease, but it has been completely eradicated (**Figure 6**).

Figure 6 The last recorded case of smallpox was in 1977.

In 2006, a vaccine was created for several strains of the human papillomavirus (HPV). HPV is spread through sexual contact and is responsible for more than 70 % of all cancers of the cervix, a part of the female reproductive system. The vaccine is considered more than 99 % effective at preventing the spread of the virus.

Unfortunately, it is not always possible to develop effective vaccines. For some diseases, such as AIDS, the structure of the virus and characteristics of the infection are obstacles to vaccine development. For other diseases, such as influenza, the virus is constantly changing, so a vaccine that works against a form of the disease in one year is unlikely to be as effective the next year.

Research This

Viral Diseases and the WHO

Skills: Researching, Analyzing, Evaluating, Communicating SKILLS HANDBOOK A2.1, A5.1

The World Health Organization (WHO) monitors and controls outbreaks of infectious diseases, such as SARS, malaria, tuberculosis, swine flu, and AIDS. Each year, they predict which viral diseases are most likely to become a serious concern. They then recommend the mass production of a vaccine for those strains. In this investigation, you will examine the role of the WHO and research a viral disease of your choice.

1. Visit the website of the World Health Organization.
2. Choose a viral disease from the WHO website and research its cause, symptoms, prevention, and treatment (if any).
3. List and describe any disease outbreaks currently being reported.

A. Summarize your findings, including the WHO recommendations about your selected disease. T/I C

B. List and summarize the current status of any other viral disease outbreaks reported by the WHO. T/I C

GO TO NELSON SCIENCE

Putting Viruses to Work

gene therapy a method of treating disease in which genes are introduced into cells to replace, supplement, or repair a defective gene

Although all viruses cause disease, they can be beneficial. As mentioned before, viruses play an important role in ecosystems. Of particular interest to humans is the role viruses play in lowering the numbers of harmful bacteria.

Recently scientists have been exploring the use of viruses in genetic engineering and in **gene therapy**—the treatment of diseases using genes. As you have learned, viruses can enter specific cells, and some can insert their own DNA into the chromosomes of the cells they infect. Scientists can therefore use viruses to deliver drugs or genes to targeted cells (**Figure 7**). They place drugs inside virus capsules or replace the viral DNA with DNA they want to insert into a host cell. This technology is still relatively new, but it is being used effectively in some applications and holds great promise in others. **Table 3** lists some possible uses of viruses in biotechnology.

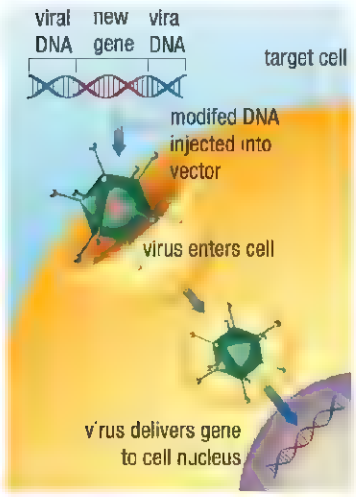


Figure 7 Viruses can be used to deliver genes and drugs to targeted cells.

Table 3 Applications of Technologies That Use Viruses

Technology	Application or possible application
using a virus capsule to deliver a drug	• This method may be used to deliver drugs to targeted cells in the body, for example, to deliver toxic chemotherapy drugs to cancerous tumour cells.
using a virus to insert a new copy of a gene	• This method may be used to insert corrective genes into individuals who suffer from a genetic disorder
using a virus to insert a gene taken from one species into another species	• This method can be used to create genetically modified organisms. • It is widely used in the genetic engineering of plants.

The use of viruses in medicine has technological problems, serious risks, and ethical concerns. Early attempts to treat people with virus therapies have had only limited success and have directly caused at least one death. The most recent trials, however, have been more promising.

Viroids and Prions

viroid a very small infectious piece of RNA responsible for some serious diseases in plants

Viroids are small, infectious pieces of RNA that were first discovered in 1971. Viroids are smaller than any virus and do not have a capsid. They also differ from viruses in that their RNA does not code for any proteins. Viroids are plant pathogens that can quickly destroy entire fields of citrus, potatoes, tomatoes, coconut palms, and other crop plants. In one case, a viroid outbreak killed more than 10 million coconut palms in the Philippines, devastating this important agricultural crop. Scientists do not know how viroids cause disease. Recent research indicates that the viroid may interfere with the normal formation and functioning of RNA within the host cell.

prion an abnormally shaped infectious protein responsible for some brain diseases of mammals, including humans

Prions, or proteinaceous infectious particles, cause a number of rare diseases in mammals. Prions are abnormally shaped proteins found in the brain and nervous tissues of infected animals. When those tissues are eaten by another animal, the prions enter that animal's bloodstream and go to its brain. In the infected animal's brain, the prions interact with normally shaped proteins, causing those proteins to change shape and become abnormal and infectious. The brains of affected animals are full of spongy holes.

Prion diseases made headlines around the world in the late 1980s when farmers in the United Kingdom reported a new disease spreading among their cattle. The disease, called bovine spongiform encephalopathy (BSE), or "mad cow disease," is estimated to have infected over 900 000 cattle in the United Kingdom. Many of those infected cattle entered the human food chain before developing symptoms. Tragically, some people who ate the contaminated meat developed a new human disease, known as variant Creutzfeldt-Jakob disease (CJD). Between 1996, when variant CJD was first described, and 2007, there were 208 cases in 11 countries. The vast majority of these cases were in the United Kingdom.

2.2 Summary

- Viruses are tiny, nonliving particles that infect cells and cause diseases.
- Viruses consist of genetic material in the form of either DNA or RNA surrounded by a capsid.
- After a virus or its genetic material enters a host cell, it takes control of the cell in order to reproduce itself.
- Phages are viruses that infect bacteria. They undergo lytic or lysogenic cycles.
- Some viruses stay dormant in their host cells for many years.
- Important human viral diseases include HIV/AIDS, influenza, measles, mumps, chicken pox, and hepatitis.
- Vaccinations have been extremely successful in reducing the incidence of many serious viral diseases.
- Viruses are being used as tools for inserting drugs or DNA into cells.
- Viroids are small, infectious pieces of RNA that cause diseases in plants.
- Prions are abnormal infectious proteins that cause disease in mammals.

2.2 Questions

1. Why are viruses considered to be non-living? K/U
2. What characteristic do viruses share with all living things? K/U
3. Which viral diseases are quite common and associated with the winter season? K/U
4. Create labelled sketches of
   (a) a virus surrounded by an envelope
   (b) a bacteriophage
   (c) the lytic cycle of a bacteriophage K/U C
5. How is the behaviour of a bacteriophage different from that of a virus that infects an animal cell? K/U
6. Explain the relationship between a virus's dormant period in a cell and the appearance of cold sores K/U
7. Give examples of viral diseases that are spread by
   (a) the bite of an animal
   (b) the exchange of bodily fluids
   (c) direct contact or through the air K/U A
8. Smallpox viruses can replicate only inside a human cell. Human influenza viruses can replicate in human cells and in the cells of pigs and some other animals. How might this difference influence the success of vaccination programs? K/U A
9. The human influenza virus H1N1—also referred to as the 2009 swine flu—was declared a pandemic by the World Health Organization. Use the Internet and other sources to answer the following questions:
   (a) What criteria does the WHO use to designate a disease outbreak as a "pandemic"?
   (b) How many deaths are thought to have resulted from this pandemic?
   (c) How many countries have reported cases of H1N1?
   (d) How did Canada respond to this outbreak? T/I
10. Viruses control populations of organisms by causing disease. Humans have also used viral diseases to control pests and invasive species. Do online research to find an example of a virus used to control rabbit populations in Australia. K/U T/I
    (a) When and why did rabbits become a problem in Australia?
    (b) Why and how were viruses used to control the rabbits?
    (c) How successful was the viral pest control?
    (d) What are some possible drawbacks of using viruses as pest control? Have any examples of these drawbacks been observed?
11. Kuru is a human prion disease discovered among some indigenous peoples of New Guinea. Research how this disease is transmitted and how long it takes to develop. T/I
12. Use the Internet and other sources to find out what routine vaccinations are currently recommended by the Ontario Ministry of Health. T/I
13. Conduct research to find out what vaccinations are recommended for travel to a tropical country of your choice. T/I
14. Dogs and cats are susceptible to a number of serious viral diseases. Check with your local veterinary clinic or go online to see what vaccinations are recommended for these pets. Report your findings to the class in a format of your choice. T/I C
15. Mumps is a potentially serious viral disease. It can cause deafness, sterility, meningitis, and encephalitis. Do online research to answer the following questions:
    (a) Why is there renewed concern about this disease when there is already a vaccination program in place?
    (b) What does "herd immunity" mean? How does it help control the spread of disease?
    (c) Why is getting the disease after puberty of particular concern to males? T/I

GO TO NELSON SCIENCE

2.3 The Protists

The smallest eukaryotes and some of the largest belong to the Kingdom Protista. This kingdom is extremely diverse. Some of its members, such as amoebas and paramecia, are very small and mobile and show complex behaviours, while others, including giant "leafy" seaweeds, are stationary and look like plants (**Figure 1**). Most are aquatic, but some are terrestrial. In this section, you will explore the rich diversity of this kingdom and gain an appreciation for the role protists play in ecosystems.

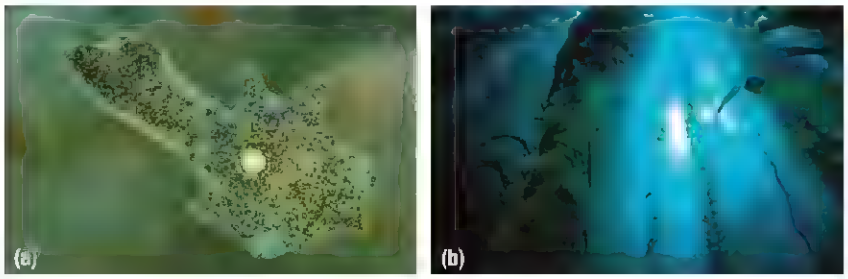


Figure 1 Protists range in size from (a) microscopic single-celled organisms to (b) giant multicellular species such as large green kelp

Why Protists Are Important

Protists play key roles in aquatic ecosystems. Protists that perform photosynthesis, along with some prokaryotes, are the major producers in the world's oceans. Non photosynthetic protists are important consumers, especially at the microscopic level, where they dominate the lowest levels of most aquatic food pyramids. Protists are abundant in moist terrestrial environments, including soil, but their ecological roles in these ecosystems are not understood as well.

Many protists are parasites—they live in, or on, other organisms. Most parasites do not harm their host organism, but some cause serious disease. Protists cause some important diseases in humans, in other animals, and in plants. On a global scale, the protist disease of greatest concern to humans is malaria, which causes more than one million deaths a year. Malaria is caused by several species of *Plasmodium*, a single-celled protist. Other serious human protist diseases are sleeping sickness and amoebic dysentery.

A less serious disease that is of significant concern in Ontario is giardiasis, or "beaver fever." Giardiasis is caused by *Giardia lamblia*, the most common intestinal parasite of humans in North America (**Figure 2**). This parasite is very common in bodies of water, including ones that are formed by beaver dams. A host becomes infected with *Giardia* by drinking contaminated water. Infections can cause abdominal pain, diarrhea, and chronic inflammation of the gut.

Some protists are valuable to humans. If you like sushi, you have eaten nori, the seaweed used to wrap sushi rolls. Nori is the common name for several species of *Porphyra*, a multicellular protist (**Figure 3(a)**). Other products made from seaweed are agar (**Figure 3(b)**) and carrageenan, both used as food additives. Seaweed products are also common in toothpastes, cosmetics, and paints.

CAREER LINK

Adventure Tour Guide

Adventure tour guides need to know how to purify water to prevent diseases. For more information about careers in adventure tour sm,

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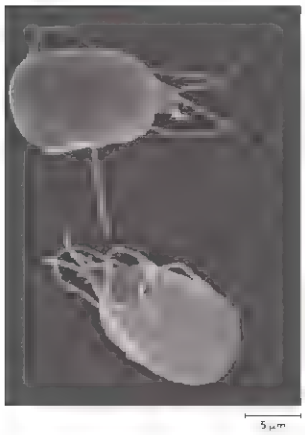

Figure 2 *Giardia lamblia* are unicellular protists that colonize and reproduce in the small intestines of some vertebrates.

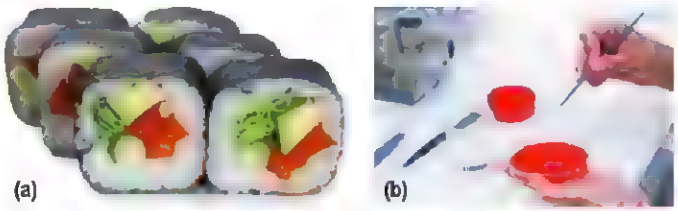

Figure 3 (a) Although *Prophyra* is sometimes green, such as the nori used to wrap sushi, it is classified as red algae. (b) Agar is a gelatinous substance derived from red algae. Microbiologists use agar as a culture medium for the growth of bacteria.

The Origins of Eukaryotes

Protists were the first eukaryotes—their cells have a nucleus and organelles bound by membranes. These internal membranes likely developed from the folded cell membrane of an ancestral prokaryotic cell (**Figure 4**). This folding would have increased the cell surface area, allowing the cell to better exchange materials with its environment. This ability is a necessary feature of large cells.

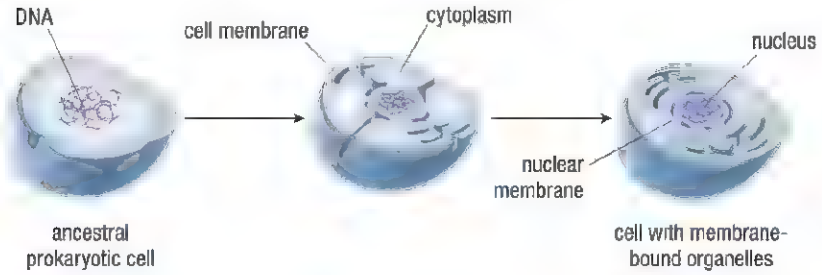

Figure 4 Internal organelles probab y developed when the cell membrane of a prokaryotic ancestor—a bacterium or archaea—folded in on itself.

Two organelles have particularly interesting origins. Consider the following information:

- Present-day mitochondria and chloroplasts each have two membranes.
- Their inner membranes are similar to those of their ancestral prokaryote, while their outer membranes match the cell membranes of the eukaryote.
- Present-day mitochondria and chloroplasts have their own internal chromosomes.
- These chromosomes are very similar to prokaryote chromosomes and contain genetic information used by the organelles.
- Mitochondria and chloroplasts reproduce independently within eukaryotic cells by binary fission, just as prokaryotes do.

Based on the evidence summarized above, mitochondria and chloroplasts are thought to have originated by endosymbiosis. **Endosymbiosis** occurs when one type of cell lives within another type of cell. According to a widely accepted theory, mitochon dria and chloroplasts were once prokaryotic organisms. These cells were engulfed by early anaerobic eukaryotic cells and incorporated into them (**Figure 5**).

endosymbiosis a relationship in which a single-celled organism lives within the cell(s) of another organism; recent findings suggest this may be very common

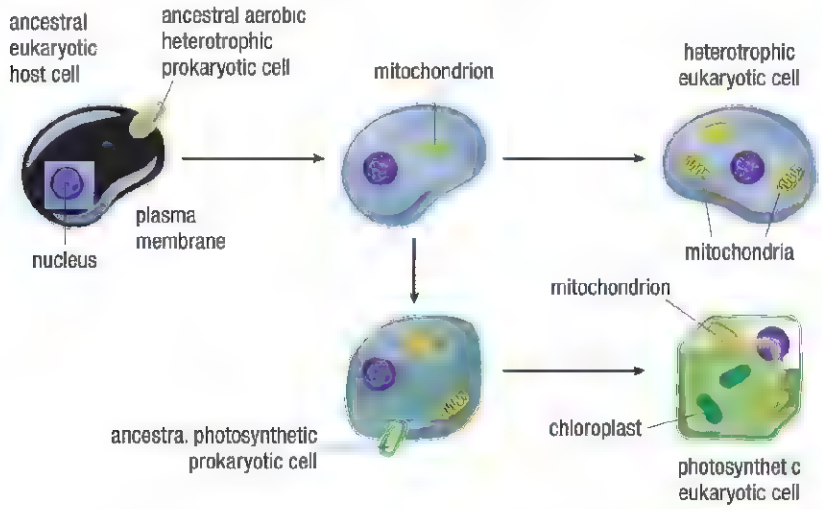

Figure 5 There is strong evidence that mitochondria and chloroplasts originated when aerobic and photosynthetic prokaryotes began living as symbiotic organisms within ancestral eukaryotic cells.

Scientists believe that mitochondria were once aerobic prokaryotes, related to modern proteobacteria. Inside the eukaryotic cells, these prokaryotes benefited from a rich food supply, while the eukaryotes benefited from the excess energy released by the aerobic prokaryotes.

Chloroplasts were likely once photosynthetic prokaryotes, related to modern cyanobacteria. Inside the early eukaryotes, these prokaryotes benefited from the carbon dioxide produced as waste by the eukaryote, which they used in photosynthesis. The eukaryotes benefited from the excess food made by the prokaryotes.

Over millions of years, these endosymbiotic prokaryotes have become permanent residents of their eukaryotic host cells and have lost their ability to live independently. They are passed on to new daughter cells when the eukaryotic cells undergo mitosis.

Recent observations suggest that endosymbiosis is much more widespread than previously suspected. Many eukaryotic organisms, including protists, plants, and animals, have prokaryotes living within some of their cells. These prokaryotes may be beneficial to the eukaryote, or they may be parasites. As you will learn in the next unit, endosymbiosis can give rise to very unusual organisms.

Classification and Phylogeny

Protists are by far the most diverse kingdom of eukaryotes—there are more than 200 000 known species. The Kingdom Protista is a traditional taxonomic group that has been used as a matter of convenience. The Animal, Plant, Fungi, Eubacteria, and Archaea Kingdoms are all based on evolutionary kinship, but the Protist Kingdom is not. Instead, this kingdom has traditionally been a "catch-all" for any species that did not fit into the other major kingdoms of life. **Figure 6** is a phylogenetic tree of the Domain Eukaryotes. Animals, Plants, and Fungi are the only branches on this evolutionary tree that are not classified as protists.

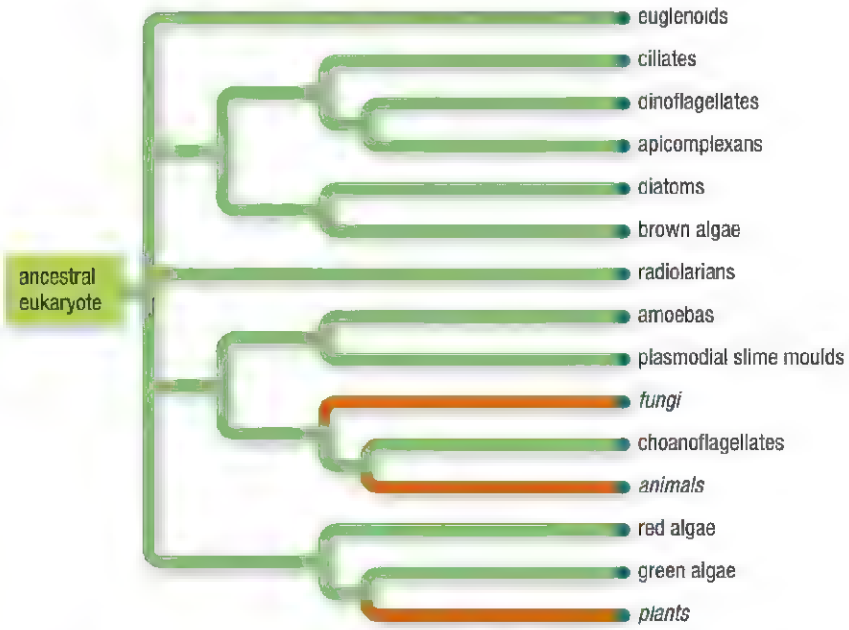

Figure 6 A phylogenetic tree of the Domain Eukaryotes. Fungi, animals, and plants are the only groups that are not included in the Protist Kingdom. The major protist groups are often only distantly related to each other. For example, amoeba are more closely related to elephants than to paramecia or kelp!

Research in the area of protist classification is very active, and more meaningful classifications will likely soon replace this single kingdom.

Investigation 2.3.1

Observing Protists (page 69)
Now that you have read about protists, you can complete Investigation 2.3.1.

In this observational study you will observe, classify, and make biological drawings of protists.

Characteristics

There is no "typical" protist. The only characteristic that all protists share is that they are not animals, plants, or fungi. In all other ways, protists vary greatly. Most are unicellular, while others are multicellular. Protists exhibit a wide variety of cell features, different ways of moving (if they move at all), different ways of getting nutrients and energy, and very different methods of reproducing.

Many protists have very complex cells (**Figure 7**). For example, heterotrophic paramecia have both macronuclei and micronuclei. Both types of nuclei contain DNA, but they play different roles in using and processing genetic information. Some protists have many copies of their chromosomes and very large amounts of DNA. Paramecia also have specialized vacuoles that contract to eliminate excess water, a gullet (similar to a mouth) for taking in food, hair-like cilia for moving, and trichocysts that release long fibres used for defence. In contrast, photosynthetic *Euglena* contain chloroplasts for performing photosynthesis. They have an eye spot for detecting light, a stiff but flexible supporting layer called a pellicle, and a large flagellum for moving.

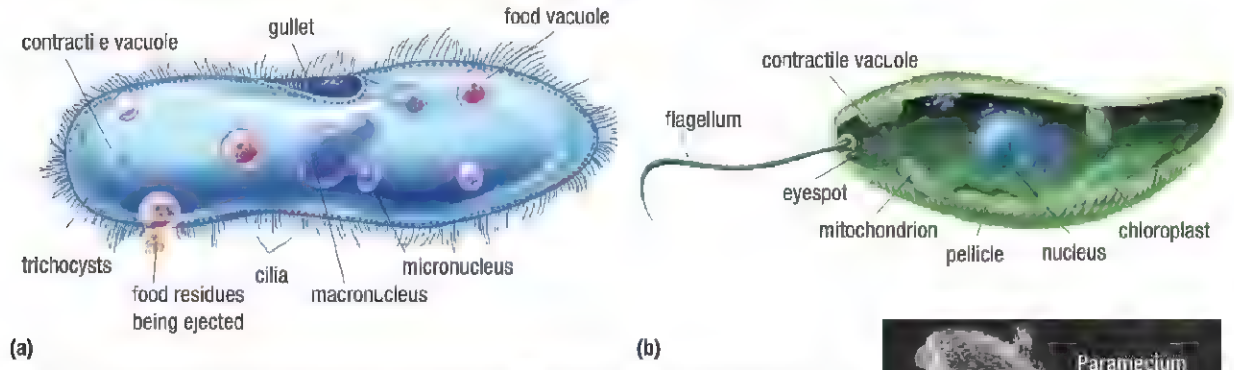

Figure 7 (a) *Paramecium*, a ciliate, and (b) *Euglena*, a euglenoid, are complex unicellular organisms.

Table 1 lists some characteristics of seven representative groups of protists.

Table 1 Characteristics of Representative Protists

Group	Energy source	Key features
euglenoids	autotrophs, photosynthetic	• They are unicellular. • They usually have two flagella for moving. • Their outer surface covering consists of stiff proteins.
ciliates	heterotrophs	• They are unicellular. • They have very complex internal structures. • They have many cilia and no cell walls (**Figure 8**).
apicomplexa	heterotrophs	• They are unicellular. • They have no cell wall. • All are parasites of animals.
diatoms	autotrophs, photosynthetic	• They are unicellular (**Figure 9**). • They move by gliding. • They are covered by glass-like silica shells.
amoebas	heterotrophs	• Some have hard outer skeletons. • They move by extensions of the cytoplasm called pseudopods
slime moulds	heterotrophs	• Their life cycles have unicellular stages and multicellular stages. • They move with flagella or pseudopods.
red algae	autotrophs, photosynthetic	• Almost all are multicellular. • They have no cilia or flagella. • Their cell walls are made of cellulose.

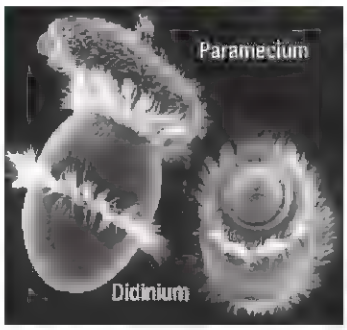

Figure 8 The ciliate *Didinium* is a voracious predator of another ciliate, *Paramecium*.

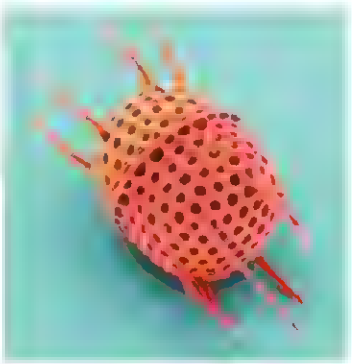

Figure 9 Diatoms are important producers in marine ecosystems.

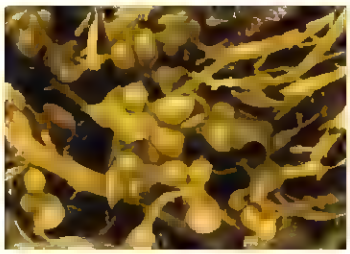

Figure 10 Gas "bladders" allow algae to float to the surface for more light.

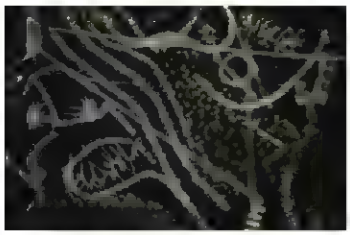

Figure 11 Phytoplankton are microscopic algae that live in marine environments. They are key to marine ecosystems, and produce about half of Earth's oxygen. The world's population of phytoplankton is thought to be declining by 1 % each year, probably because of warming ocean temperatures.

Interactions in Ecosystems

Protists play key roles in ecosystems as producers or consumers. For example, the large green, red, and brown algae called seaweeds have gas-filled bladders that help them float toward the light (**Figure 10**). This allows them to produce energy through photosynthesis. Photosynthetic protists are the primary producers in aquatic food webs. The large kelps, belonging to the brown algae group, can grow up to a half metre a day and reach a length of 80 m!

Climate change is affecting many protists, including algae (**Figure 11**). In aquatic ecosystems the temperatures of oceans and lakes are rising. The water is also becoming more acidic, which may interfere with some protists' ability to produce their outer protective shells. Without their protective shells, they may not survive. The loss of these protists may severely damage food webs that rely on the photosynthetic protists as the primary producers. Warmer water temperatures may also allow the population sizes of some species to increase, which can also interfere with natural food webs in unpredictable ways.

Some protists live as symbiotic organisms in the bodies of animals. Corals are a diverse group of animals responsible for building coral reefs. For food, corals rely on symbiotic photosynthetic protists called zooxanthellae that live within their bodies. Corals are not well understood, but we know that if the corals are stressed by pollution or unusually warm water temperatures, the zooxanthellae lose their green chlorophyll pigment and cannot perform photosynthesis. The coral then take on a bleached white appearance and will die if the condition persists.

Other symbiotic protists are parasites. *Plasmodium*, the parasitic protist that causes malaria, is an example of this. Malaria is spread from person to person by the bite of mosquitoes of the genus *Anopheles*. Since these mosquitoes cannot survive winter in cold climates, malaria is generally found only in tropical and subtropical climate zones. Climate change is already causing warmer temperatures in areas that were too cold for these mosquitoes to survive. As a result, cases of malaria may be found in new areas.

Life Cycles

Single-celled protists reproduce asexually and sexually. Asexual reproduction involves simple binary fission—the cell divides into two genetically identical daughter cells. When a paramecium undergoes binary fission, the macronucleus is elongated and then divides (**Figure 12(a)**). The micronuclei and other organelles are divided approximately equally between the two daughter cells.

Sexual reproduction of many unicellular protists involves conjugation—cells align and exchange genetic material. In a paramecium, conjugation involves the exchange of special micronuclei (**Figure 12(b)**).

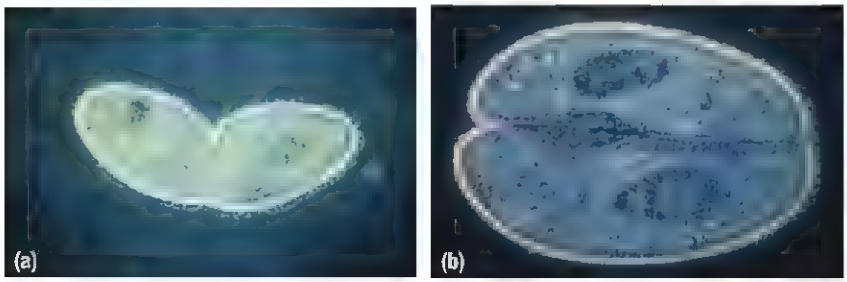

Figure 12 Paramecia reproduce (a) asexually by binary fission and (b) sexually by conjugation.

haploid a cell containing half the usual complement of chromosomes (*n*)

zygote a cell formed by the fusion of two sex cells; the zygote is diploid (2*n*)

diploid a cell containing two copies of each chromosome (2*n*)

Multicellular protists have more complex life cycles. Sexual reproduction in multicellular protists may involve the formation of sex cells—male sperm cells and female eggs. These sex cells contain only half the usual number of chromosomes; they are **haploid**. When a sperm cell fuses with an egg, the resulting cell is called a **zygote**. Most zygotes have two copies of every chromosome—one copy from the sperm and one copy from the egg. This makes the zygote **diploid**.

The life cycle of brown algae is quite different, because it alternates between a diploid stage and a haploid stage (**Figure 13**).

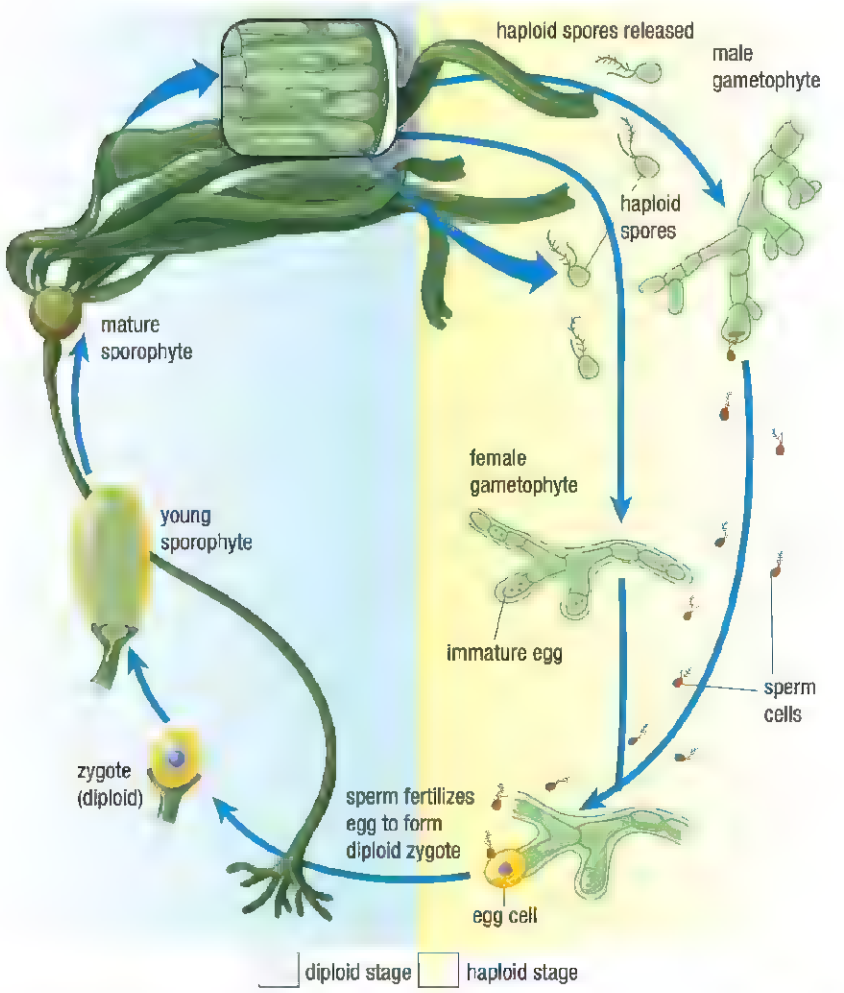

Figure 13 Brown algae have a life cycle that alternates between a diploid stage and a haploid stage.

The large brown alga is a diploid **sporophyte** that produces and releases single celled haploid **spores**. These spores then find and attach to a surface and begin dividing and growing into multicellular haploid **gametophytes**. These gametophytes eventually produce haploid sperm and eggs. When an egg is fertilized by a sperm, it becomes a diploid zygote that grows into a multicellular sporophyte. This type of life cycle, with both diploid sporophyte and haploid gametophyte stages, is called an **alternation of generations**.

It should be emphasized that in species that exhibit an alternation of generations, both asexual and sexual reproduction are needed to complete a full life cycle. This is in contrast to many other species that reproduce both asexually and sexually.

Consider the example of hydra that can reproduce asexually by forming buds. These buds grow into adult hydras that resemble the original parent organism. Hydra can also reproduce sexually, with a fertilized egg growing into an adult that also resembles the original adult. In this way, asexual and sexual reproduction represent two *different* ways of completing a life cycle.

sporophyte a diploid organism that produces haploid spores in an alternation of generations life cycle

spore a haploid reproductive structure; usually a single cell; capable of growing into a new individual

gametophyte a haploid organism that produces haploid sex cells in an alternation of generations life cycle

alternation of generations a life cycle in which diploid individuals produce spores that create haploid individuals; the haploid individuals reproduce sexually, producing sporophyte individuals and completing the cycle

Brown algae are producers, capable of living independently and making their own food. At the other extreme are parasitic organisms that are completely dependent on other organisms. **Figure 14** illustrates a simplified diagram of the life cycle of *Plasmodium*, the protist that causes malaria.

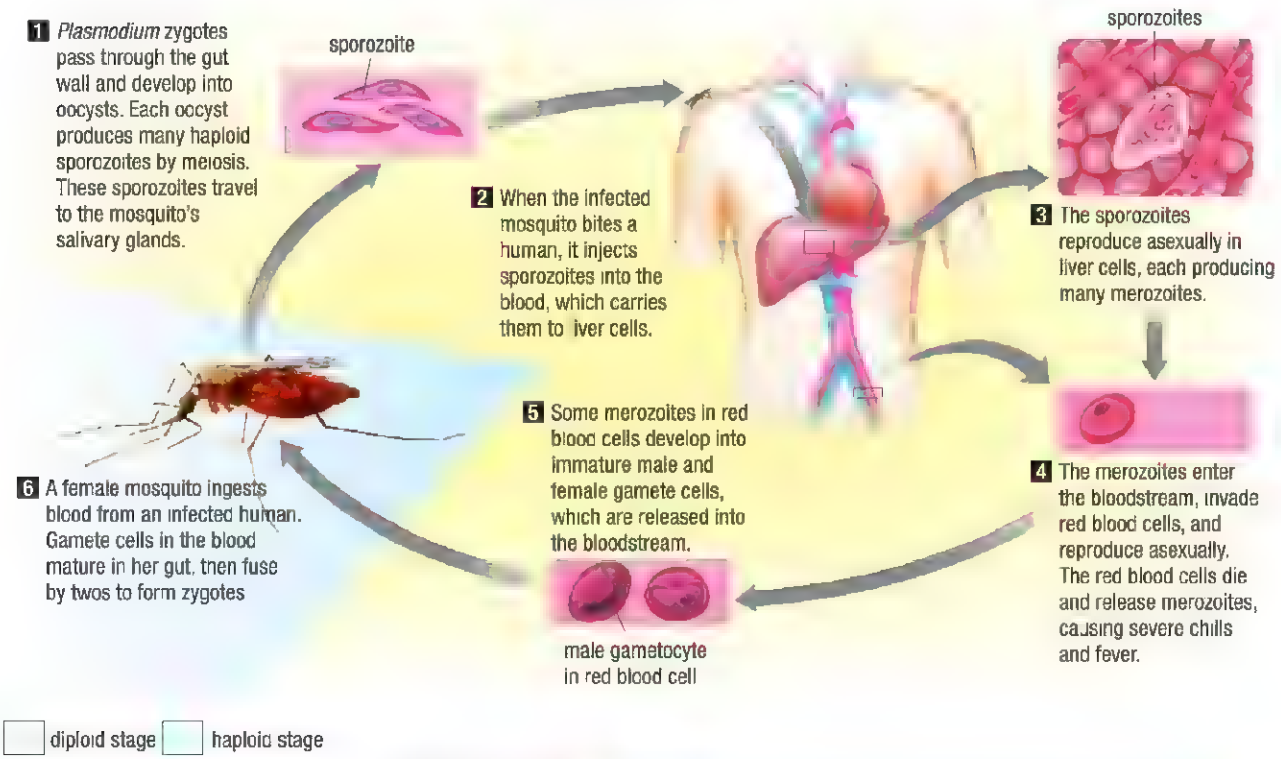

Figure 14 The life cycle of *Plasmodium*

CAREER LINK

Protistologists

Scientists who specialize in research on protists are called protistologists. To find out more about becoming a protistologist,

GO TO NELSON SCIENCE

Research This

Protistology

Skills: Researching, Analyzing, Evaluating, Communicating SKILLS HANDBOOK A2.1, A5.1

The diversity of protists is truly remarkable. They vary dramatically in size and shape, in their ecological roles, and in their significance to humans. In this activity you will research and explore some of this protist variety.

1. Search for and view online video clips of protists moving and feeding using (i) flagella, (ii) cilia, and (iii) pseudopodia (extensions of their cytoplasm; singular: pseudopod). Describe how these structures allow protists to move and feed.
2. Investigate the life cycle of *Plasmodium vivax*. Describe how this parasite makes use of mosquitoes, liver cells, and blood cells to complete its life cycle.
3. Potato blight is an important plant disease that causes billions of dollars in crop losses every year. It was also the main cause of the famous Irish Potato Famine. Do research and answer the following questions:

A. Which protist is responsible for this disease? How does the protist affect potato plants? K/U T/I

B. Genetic engineers have recently inserted a gene from another plant into potatoes to create potatoes that are resistant to the disease. What plant did scientists take this gene from? T/I

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2.3 Summary

- Protists are extremely diverse eukaryotic species that are mostly unicellular. Most are aquatic.
- Protists are important producers and consumers in many ecosystems.
- Some protists are responsible for serious human diseases, including malaria.
- Eukaryote nuclei are thought to have evolved by the folding in of the cell membrane. This was followed by the acquisition of mitochondria and chloroplasts through the process of endosymbiosis.
- The Protist Kingdom includes all the eukaryotes that are not fungi, plants, or animals
- Protists vary dramatically in cellular structure, metabolism (energy sources), how they move, and life cycles.
- Warming temperatures and increased water acidity can harm some protists and threaten major aquatic food webs.
- Some protist life cycles include an alternation of generations with both sporophyte and gametophyte individuals.

UNIT TASK BOOKMARK

As you work on the Unit Task, consider how your chosen group of organisms and the other organisms it interacts with are affected by climate change.

2.3 Questions

1. Choose and describe four examples of different protists that highlight the diversity within this kingdom. K/U
2. Some protists are more closely related to animals, plants, or fungi than they are to each other. What does this suggest about the classification criteria used for members in this kingdom? K/U A
3. Give an example of a protist that is
   (a) a parasite of humans
   (b) very large and photosynthetic
   (c) a unicellular species with two flagella and photosynthetic
   (d) covered in cilia
   (e) surrounded by a silica shell K/U A
4. Explain how a warming climate might lead to the spread of malaria. K/U A
5. How does an increase in acidity harm some protists with shells? K/U
6. Distinguish between each of these terms:
   (a) haploid and diploid
   (b) zygote and spore
   (c) gametophyte and sporophyte K/U
7. Create labelled sketches in your notebook to illustrate
   (a) the formation of the nucleus in ancient eukaryotic cells
   (b) the evolution of mitochondria and chloroplasts by the process of endosymbiosis K/U C
8. Slime moulds are among the most unusual protists. Use the Internet and other sources to learn more about slime moulds. T/I
   (a) Describe and compare plasmodial slime moulds and cellular slime moulds.
   (b) What roles do slime moulds play in ecosystems?
   (c) Watch online video clips of slime mould motion. Describe what you see.
9. African sleeping sickness is a serious parasitic disease caused by the protist *Trypanosoma brucei* (**Figure 15**). Use the Internet and other sources to find out more about this disease.
   (a) Where in the world is it most prevalent?
   (b) How is it spread?
   (c) What are the symptoms?
   (d) Can the disease by effectively treated? T/I

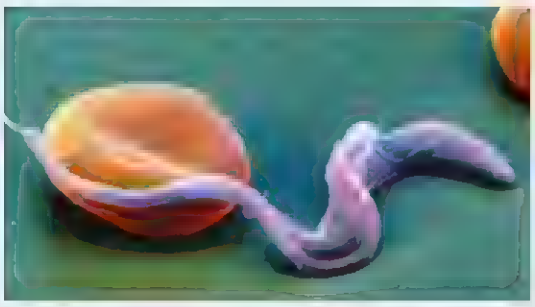

Figure 15 *Trypanosoma brucei* causes sleeping sickness.

10. Some protists are considered colonial organisms. Research the criteria that biologists use to distinguish between colonial and multicellular organisms. Summarize your findings. T/I
11. Use the Internet and other sources to research some uses of protist products. T/I
    (a) What properties of agar and carrageenan make them valuable?
    (b) List five or more uses for agar and carrageenan.
    (c) What is diatomaceous earth?
    (d) List five or more uses for diatomaceous earth.

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CHAPTER 2 Investigations

Investigation 2.1.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Observing Bacteria

Bacteria are often thought of simply as "germs." However, some bacteria are not only beneficial but also nutritious. In this investigation, you will examine a culture of living bacteria in a common food as well as prepared slides of several different types of bacteria. You will observe the bacteria and make biological drawings of what you see.

Purpose

To observe and identify basic types of bacteria and document your findings with proper biological drawings

Equipment and Materials

- eye protection
- apron
- microscope
- active plain yogurt culture (unpasteurized)
- toothpick and eyedropper
- microscope slides and cover slips
- prepared slides of assorted bacteria types

Even though you will be working with yogurt in this investigation, you must follow standard laboratory safety procedures. NEVER CONSUME ANY FOOD ITEMS in the lab.

Procedure

1. Put on your eye protection and apron. Get a small sample of live yogurt culture. Read the label on the container to find out what type (or types) of bacteria are in the culture.
2. Use a toothpick to transfer a small amount of the yogurt to a clean microscope slide. Prepare a wet mount of the sample by adding one or two drops of water and a cover slip.
3. Observe the culture under the microscope using low, medium, and high power. Make a biological drawing of the bacteria you see.
4. Obtain a prepared slide (or slides) containing three types of stained bacteria. Observe the bacteria under low, medium, and high power. Make biological drawings of the three types of bacteria.

Analyze and Evaluate

(a) What shapes of bacteria did you observe: cocci, bacilli, or spirilla? K/U T/I

(b) What features of the bacteria, other than shape, were you able to distinguish? K/U T/I

(c) What other possible sources of bacteria could be used in this investigation? K/U T/I A

Apply and Extend

(d) What difficulties, if any, did you have in examining these bacteria? Why do you think the identification and classification of bacteria is particularly difficult? T/I

(e) People who are lactose intolerant have trouble digesting milk and some milk products, but they often have less trouble digesting yogurt. Suggest a possible explanation for this observation. T/I A

(f) Many kinds of bacteria are used in the production of foods. Use the Internet and other sources to find out more about the use of bacteria in cheese and chocolate production. Share your findings with the class. T/I C

(g) There is now a growing interest in foods containing "probiotics." Use the Internet and other sources to answer the following questions: T/I

(i) What are probiotics? Why are they considered beneficial?

(ii) Which types of foods typically contain probiotics?

(iii) Are any risks associated with the consumption of probiotics?

GO TO NELSON SCIENCE

Investigation 2.3.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Observing Protists

Protists are an extraordinarily diverse group of living things. They range from single-celled parasites to giant photosynthetic kelp that are tens of metres long. In this activity you will observe some of this diversity by examining living and preserved protists. You will classify the protists and make biological drawings to record your findings.

Purpose

To observe, classify, and make biological drawings of a variety of protists

Equipment and Materials

- eye protection
- apron
- microscope
- microscope well slides
- cover slips
- samples or cultures of living protists
- methylcellulose (slowing agent)
- identification keys or guides for common protists
- stained yeast culture (Congo red)
- prepared slides of protists

Wash your hands carefully after handling any biological material.

Procedure

1. Put on your eye protection and apron.
2. Place a sample (two or three drops) of living protists in a well slide and cover with a cover slip. If well slides are not available, make a wet mount of the sample and place a small object (such as a piece of toothpick) under the cover slip to keep it from crushing the protists.
3. Examine the living protists under the microscope using low and medium power. Do not use high power.
4. If the protists are moving too quickly to observe easily, lift the cover slip and add a drop of methylcellulose.
5. Create a simple sketch of each type of protist you observe.
6. For each type of protist you observe, make a short list of its key characteristics: relative size, mobility, colour (if any), shape, and behaviour. Record this information in a table.
7. Use the identification keys to classify each protist. Once you have classified each protist, use this information to label the sketches you made in Step 5.
8. Prepare a second slide of living protists and add a small drop of the stained yeast culture. Observe the protists for evidence that they are feeding on the yeast cells.
9. Obtain a prepared slide (or slides) of two or three different protists and observe them under low, medium, and high power. Use the identification keys to classify each one.
10. Choose two protists and create a biological drawing of each.

Analyze and Evaluate

(a) Describe the overall diversity of the protists you examined. T/I C

(b) Was there evidence that some of these protists could perform photosynthesis? Explain. K/U T/I A

(c) Describe any evidence of feeding that you observed. T/I

(d) Comment on any difficulties you experienced observing moving protists and on the benefits of using methylcellulose. T/I

Apply and Extend

(e) The diameter of the low-power field in most high school microscopes is about 1.4 mm. Based on your observations, estimate how long it would take a fast-moving protist to travel across one full field diameter. Use your estimate to calculate how long it would take the same protist to cover a distance of 1 m if it travelled in a straight line. Do you think protists are fast-moving or slow-moving organisms? T/I A

(f) Most protists live in aquatic environments. How might this influence their structure and behaviour? T/I A

CHAPTER 2 SUMMARY

Summary Questions

1. Create a study guide based on the Key Concepts listed at the beginning of the chapter, on page 44. Divide the guide into four parts: Eubacteria, Archaea, Viruses, and Protists. Make a bulleted list of the key characteristics of each group, its important roles in the environment, and the ways it can harm and/or benefit humans. Include a labelled sketch of a representative example from each group.
2. Look back at the Starting Points questions at the beginning of the chapter, on page 44. Answer these questions using what you have learned in this chapter. Compare your answers with those that you gave at the beginning of the chapter. How has your understanding changed? What new knowledge and skills do you have?

Vocabulary

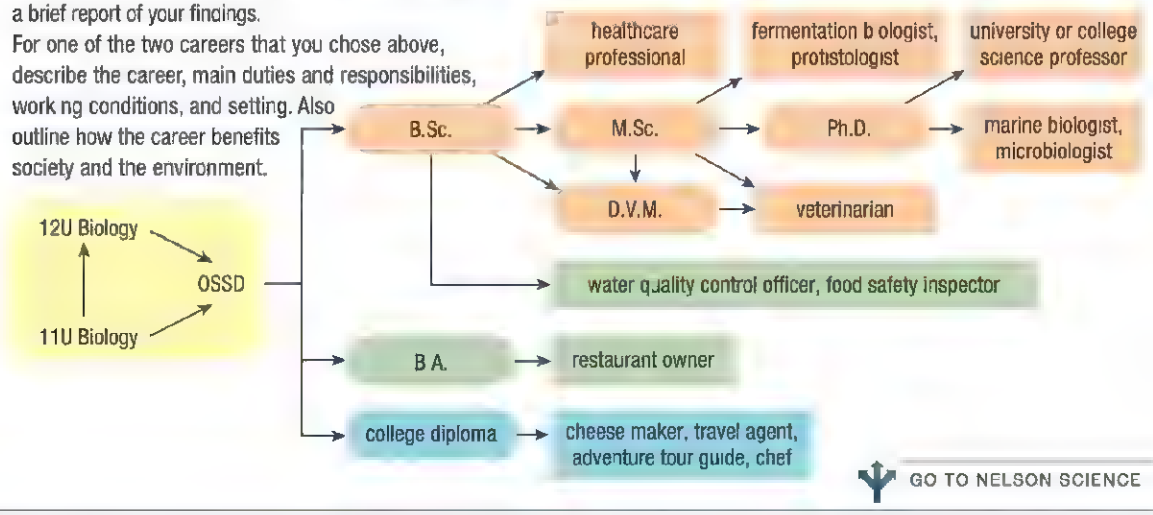
pathogen (p. 46)
mutualism (p. 47)
antibiotic (p. 47)
plasmid (p. 49)
capsule (p. 49)
coccus (p. 49)
bacillus (p. 49)
spirillum (p. 49)
inorganic chemical (p. 49)
organic chemical (p. 49)
obligate aerobe (p. 49)
facultative aerobe (p. 49)
fermentation (p. 49)
obligate anaerobe (p. 49)
binary fission (p. 49)
conjugation (p. 50)
transformation (p. 50)
horizontal gene transfer (p. 50)
endospore (p. 50)
virus (p. 54)
capsid (p. 54)
RNA (ribonucleic acid) (p. 54)
epidemic (p. 54)
pandemic (p. 54)
bacteriophage (p. 55)
lysis (p. 56)
lysogeny (p. 56)
transduction (p. 56)
gene therapy (p. 58)
viroid (p. 58)
prion (p. 58)
endosymbiosis (p. 61)
haploid (p. 64)
zygote (p. 64)
diploid (p. 64)
sporophyte (p. 65)
spore (p. 65)
gametophyte (p. 65)
alternation of generations (p. 65)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or postgraduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select two careers related to the study of prokaryotes, viruses, and protists that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



GO TO NELSON SCIENCE

CHAPTER 2 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which of the following statements is true about prokaryotes? (2.1) K/U
   (a) Prokaryotes play important roles in ecosystems.
   (b) Prokaryotes are microscopic organisms.
   (c) Prokaryotes have a number of commercial applications.
   (d) all of the above
2. What is the key difference between autotrophic bacteria and heterotrophic bacteria? (2.1) K/U
   (a) They obtain nutrients and energy in different ways.
   (b) Autotrophic bacteria cause disease, and heterotrophic bacteria do not.
   (c) They use different methods of reproduction.
   (d) Their physical appearance is different.
3. Where would you be most likely to find an archaea that is classified as a methanogen? (2.1) K/U
   (a) a sewage lagoon
   (b) the Dead Sea
   (c) a hydrothermal vent
   (d) the Arctic Ocean
4. Which of the following organisms are targets for viruses? (2.2) K/U
   (a) animals
   (b) bacteria
   (c) plants
   (d) all of the above
5. Which of the characteristics listed below can be used to describe all viruses? (2.2) K/U
   (a) contain RNA
   (b) cause cancer
   (c) contain DNA
   (d) are infectious agents
6. Which statement correctly describes a way in which viruses are different from living things? (2.2) K/U
   (a) They are classified into genera and species.
   (b) They do not produce or use energy.
   (c) They reproduce and pass on genetic information.
   (d) They contain proteins.
7. Which of the following best describes the Protist Kingdom? (2.3) K/U
   (a) The organisms that it classifies all have close evolutionary relationships.
   (b) It includes some animals and some plants.
   (c) The organisms that it classifies are not always closely related.
   (d) The organisms that it classifies are all very similar.
8. Which group of protists is characterized by silica shells? (2.3) K/U
   (a) euglenoids
   (b) ciliates
   (c) diatoms
   (d) slime moulds
9. Which term best describes a life cycle that includes a diploid sporophyte stage and a haploid gametophyte stage? (2.3) K/U
   (a) alternation of generations
   (b) asexual reproduction
   (c) binary fission
   (d) sexual reproduction
10. Which kingdoms have both members that are entirely photosynthetic and those that are entirely non photosynthetic? (2.1, 2.3) K/U
    (a) Kingdom Archaea, Kingdom Eubacteria
    (b) Kingdom Eubacteria, Kingdom Protista
    (c) Kingdom Archaea, Kingdom Protista
    (d) Kingdom Archaea, Kingdom Eubacteria, Kingdom Protista

Indicate whether the statement is true or false. If you think the statement is false, rewrite it to make it true.

11. Prokaryotes are found in few habitats on Earth. (2.1) K/U
12. Photosynthetic bacteria are important producers in marine ecosystems. (2.1) K/U
13. Bacteria that cannot live in environments with oxygen are classified as facultative anaerobes. (2.1) K/U
14. Bacteria produce endospores to help them survive in favourable environmental conditions. (2.1) K/U
15. The capsule of protein surrounding a virus is called a capsid. (2.2) K/U
16. Most species of viruses can infect only a single host species. (2.2) K/U
17. Lysis is the rupturing of a host cell when newly made viruses are released. (2.2) K/U
18. Malaria is an example of a disease caused by a protist. (2.3) K/U
19. Red algae are photosynthetic protists. (2.3) K/U
20. The Protist Kingdom is the least diverse kingdom of eukaryotes. (2.3) K/U

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CHAPTER 2 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. What characteristic causes a type of bacteria to be classified as a pathogen? (2.1) K/U
   (a) It is rod shaped.
   (b) It has flagella.
   (c) It causes disease.
   (d) It requires oxygen to live.
2. Which of the following characteristics is shared by all obligate aerobes? (2.1) K/U
   (a) They are spiral shaped.
   (b) They require oxygen.
   (c) They have antibiotic resistance.
   (d) They reproduce asexually.
3. Which of the following diseases is caused by a type of bacteria? (2.1) K/U
   (a) malaria
   (b) tuberculosis
   (c) chicken pox
   (d) rabies
4. Conjugation, transformation, and horizontal gene transfer are three processes that increase what? (2.1) K/U
   (a) the metabolism of bacteria
   (b) the reproductive rate of bacteria
   (c) the genetic diversity of bacteria
   (d) the rate of photosynthesis in bacteria
5. Which of the following viral diseases is transmitted through the air? (2.2) K/U
   (a) common cold
   (b) mumps
   (c) HIV/AIDS
   (d) rabies
6. In gene therapy, which of the following can be used to deliver genes to targeted cells? (2.2) K/U
   (a) archaea
   (b) bacteria
   (c) viruses
   (d) amoebas
7. Prions cause disease in
   (a) bacteria
   (b) viruses
   (c) plants
   (d) animals (2.2) K/U

Match each term on the left with the most appropriate description on the right.

8.

(a) red algae	(i) unicellular, usually have two flagella
(b) amoebas	(ii) move using pseudopods
(c) ciliates	(iii) multicellular, photosynthetic
(d) euglenoids	(iv) move using cilia
(e) slime moulds	(v) life cycle includes multicellular and unicellular stages (2.3) K/U

Indicate whether the statement is true or false. If you think the statement is false, rewrite it to make it true.

9. Most bacteria have a very slow rate of reproduction. (2.1) K/U
10. Photosynthetic bacteria are decomposers in many ecosystems. (2.1) K/U
11. Chlamydia is a sexually transmitted infection that is caused by prions. (2.1, 2.2) K/U
12. Flagella are structures of bacteria used in protein synthesis. (2.1) K/U
13. Binary fission is a form of asexual reproduction. (2.1) K/U
14. Archaea inhabit extreme environments, such as extremely hot or cold areas. (2.1) K/U
15. HIV/AIDS is a disease caused by a virus. (2.2) K/U
16. Bacteriophages are a type of protist. (2.2) K/U
17. Smallpox and human papillomavirus are two diseases that can be prevented with antibiotics. (2.2) K/U
18. Viroids are classified as living things. (2.2) K/U
19. Prions are abnormally shaped proteins that can cause disease. (2.2) K/U
20. Agar and carrageenan are food additives made from seaweed. (2.3) K/U
21. Conjugation is a process involved in the asexual reproduction of unicellular protists. (2.3) K/U

Understanding

Write a short answer to each question.

22. Although prokaryotes have a great impact on humans and other living things on Earth, our understanding of prokaryotes is very limited. (2.1) K/U A
    (a) Identify two specific factors that limit scientists' ability to learn more about prokaryotes.
    (b) Describe one specific way in which increased knowledge of prokaryotes could benefit humans.

23. (a) Identify and describe one specific way that bacteria *directly* affect human health.
    (b) Identify and describe one specific way that bacteria *indirectly* affect human health. (2.1) K/U
24. (a) Identify and describe two specific roles of bacteria in food webs.
    (b) Briefly explain the role of bacteria in the nitrogen cycle. (2.1) K/U
25. Scientists do not know as much about archaea as they do about bacteria. Identify two specific reasons for this. (2.1) K/U
26. Many organisms rely on mutualistic relationships with other species to ensure their success. Provide examples of mutualism between prokaryotes and eukaryotes to support this statement. (2.1) K/U A
27. Identify the two domains of life that are thought to share the most recent common ancestor. (2.1) K/U
28. Bacteria are classified into groups based on their characteristics. (2.1) K/U A
    (a) Which group would a bacterium with spiral-shaped flagellum in its cytoplasm belong to?
    (b) Describe one other specific characteristic you would expect this bacterium to display, based on the group into which it is classified.
29. Bacteria often have structures called flagella and pili. (2.1) K/U T/I
    (a) Compare and contrast the structures of flagella and pili.
    (b) Contrast the functions of flagella and pili.
30. Describe the structure of a bacterial cell wall. (2.1) K/U
31. Describe an investigation that a scientist could carry out to find out whether a type of bacteria is autotrophic or heterotrophic (2.1) K/U T/I
32. Binary fission is the normal mode of reproduction in prokaryotes. (2.1) K/U
    (a) Describe the process of binary fission.
    (b) Identify the outcome, or products, of binary fission.
33. Explain why conjugation is classified as a form of sexual reproduction. (2.1) K/U
34. Write a sentence that relates the speed at which bacteria reproduce to the rate at which they experience mutations. (2.1) K/U T/I
35. It is easy to understand how antibiotics that kill bacteria can benefit humans, but why do some bacteria produce antibiotics? How can one kind of bacteria benefit from killing another? (2.1) K/U
36. Describe the role of horizontal gene transfer in creating the deadly *E. coli* strain O157:H7. (2.1) K/U
37. Archaea differ from other living things in several ways. (2.1) K/U
    (a) Describe how the structure of the cell walls and cell membranes of archaea differ from the cell walls and cell membranes of other living things.
    (b) Relate these differences to the ability of archaea to live in extreme environments.
38. Give three specific examples of environments in which you would expect to find archaea rather than bacteria. (2.1) K/U
39. Explain how viruses can be beneficial in ecosystems. (2.1) K/U T/I
40. Explain the difference between an epidemic and a pandemic. (2.2) K/U
41. Describe how infection with certain types of viruses can lead to the development of cancer. (2.2) K/U
42. Restate in your own words three different hypotheses that have been proposed to explain the origin of viruses. (2.2) K/U
43. Identify and label the structures shown in **Figure 1(a)** and **(b)**. (2.1, 2.2) K/U

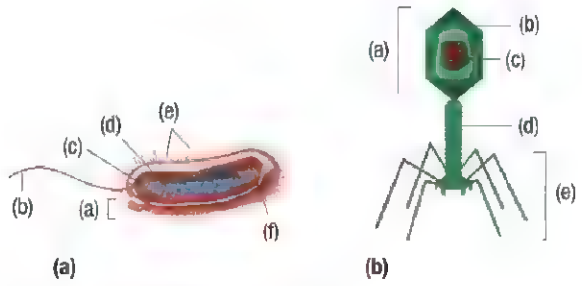


Figure 1 (a) A bacteria cell and (b) a virus

44. Viruses are non-living. Among the differences between viruses and living things is the fact that viruses do not have life cycles. Instead, viruses have infectious cycles. (2.2) K/U T/I
    (a) Identify three key steps in the infectious cycle of all viruses.
    (b) Summarize the difference between a lytic cycle and a lysogenic cycle.
45. Protists are a diverse group of organisms. Protists affect humans and ecosystems in a wide variety of ways. (2.3) K/U
    (a) Identify and describe two roles of protists in food chains and food webs.
    (b) Identify two human diseases caused by protists.
    (c) Identify two ways that protists are useful to humans.

46. Internal membranes are a characteristic of eukaryotic cells, including those of protists. (2.3) K/U
    (a) The ancestral prokaryotic cells from which eukaryotic cells developed did not have internal membranes. Explain how these membranes most likely developed.
    (b) Identify the advantage of the development of these membranes.
47. Imagine you are researching a protist classified into the group Apicomplexa. (2.3) K/U T/I A
    (a) Based on its classification into the group Apicomplexa, predict two specific structural characteristics that the protist will have.
    (b) Based on its classification, predict how this organism gets the nutrients and energy it needs to survive.
48. Coral reefs are important ocean ecosystems. Many living things depend on corals for shelter. (2.3) K/U T/I A
    (a) Classify and describe the relationship between corals and zooxanthellae.
    (b) Describe how global increases in ocean temperature affect zooxanthellae.
    (c) Predict how a sustained rise in Earth's ocean temperatures could affect coral reef ecosystems.
49. Brown algae undergo a life cycle that is called alternation of generations. Summarize the steps of this type of life cycle by labelling and describing the events and structures in **Figure 2**. (2.3) K/U

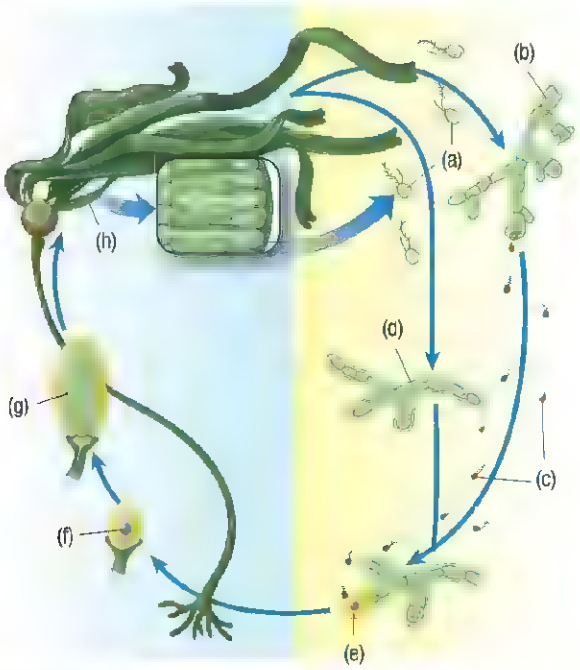


Figure 2 The life cycle of brown algae

50. Malaria is a disease in humans that causes more than a million deaths each year. (2.3) K/U
    (a) Identify the specific protist that causes malaria.
    (b) Explain how malaria is spread.
    (c) Explain how climate change is causing a change in the locations where malaria occurs.

Analysis and Application

51. Technology and science are closely intertwined. There are many examples of advances in science that have affected technology and advances in technology that have affected science. (2.1) T/I A
    (a) Explain how the discovery of micro-organisms illustrates the relationship between science and technology.
    (b) Predict how advancements in scientific research on micro-organisms could affect a specific technology in the future, or vice versa.
52. Prokaryotes are the dominant form of life in many habitats on Earth. Analyze and describe how the range of environments in which bacteria can live relates to their dominance as a life form on Earth. (2.1) T/I
53. Predict how the level of atmospheric oxygen would change if the population of photosynthetic marine bacteria greatly increased. Explain your prediction. (2.1) T/I A
54. Antibiotics are used to treat bacterial infections. Explain why antibiotics might affect vitamin levels in the body. (2.1) A
55. A researcher studying an ecosystem found that the great majority of a certain species of bacteria in the ecosystem had endospores surrounding their chromosomes. (2.1) T/I A
    (a) Based on this information, infer whether the conditions in the ecosystem are favourable or unfavourable for this type of bacteria.
    (b) Explain the reasoning you used to develop this response.
56. Termites are a type of insect that consume wood. Bacteria in their intestines help them digest the wood. (2.1) T/I A
    (a) Identify the specific group of bacteria found in termite intestines.
    (b) Compare the role of these bacteria with the role of bacteria found in the human digestive system.

57. Imagine that you work in a research laboratory and have just discovered two types of bacteria. Use the characteristics below and your knowledge of the shapes and arrangements of bacteria cells to name the following: (2.1) T/I A
    (a) a rod-shaped bacteria typically found in paired cells
    (b) a round bacteria found in clumps of cells
58. Apply what you know about the metabolism of bacteria to explain why facultative aerobes have an adaptive advantage over obligate aerobes and obligate anaerobes in many environments. (2.1) T/I A
59. Predict how the effectiveness of existing antibiotics may change in the next 10 years. Write one or two sentences giving specific information that supports your prediction. (2.1) T/I A
60. In recent years, there have been many incidents when computer viruses have affected computers around the world. Identify two ways that computer viruses are analogous to actual viruses. (2.2) A
61. Scientists believe there are millions of species of viruses on Earth. (2.2) A
    (a) Identify the approximate number of species of viruses that have been identified.
    (b) How do you think human understanding of viruses will change as a larger percentage of virus species are identified and studied?
62. A human who gets bitten by a dog might have to undergo immunization for rabies. What unusual characteristic of the rabies virus does this fact relate to? (2.2) A
63. (a) Identify one way that bacteriophages are similar to other types of viruses.
    (b) Identify one way that bacteriophages are different from other types of viruses. (2.2) A
64. (a) Identify two ways that vaccines and antibiotics are similar.
    (b) Identify two ways that vaccines and antibiotics are different. (2.1, 2.2) A
65. Imagine that time has passed and you are now an adult and have children of your own in high school. When you look through your child's biology textbook, you see that the Kingdom Protista is no longer used as a classification for organisms. You also note that great advances have been made in genetic analysis. Explain how these observations are probably related. (2.3) T/I A
66. A scientist states that placing an organism in the Kingdom Protista is "a process of elimination." Explain why this is an appropriate phrase to describe how organisms are classified as protists. (2.3) T/I
67. A scientist has discovered a protist that is autotrophic—it carries out photosynthesis. He will use his observations to determine into which category of protists the newly discovered protist should be classified. (2.3) K/U T/I A
    (a) Based on the fact that the protist is an autotroph that carries out photosynthesis, identify three protist groups to which the newly discovered protist could belong.
    (b) The scientist then determined that the protist is unicellular rather than multicellular. Identify two groups to which the protist might belong.
    (c) The scientist further analyzed the protist and found that it moves by gliding and does not have flagella. Identify the group to which the protist belongs.
    (d) What is one additional characteristic the scientist could examine that would allow him to confirm this classification?
68. Green, brown, and red algae have gas bladders that make them more buoyant in water. (2.3) K/U T/I A
    (a) Explain how the ability of these organisms to get the energy they need is related to the function of the gas bladders.
    (b) Predict what would happen to an individual alga if its gas bladders were damaged. Explain your prediction.
69. Diatomaceous earth is a sedimentary rock made up of fossilized fragments of diatoms. The rock can be easily crushed into a powder and is used in several commercial applications. What characteristic of diatoms makes diatomaceous earth a good abrasive? (2.3) A
70. (a) Identify two similarities shared by prokaryotes, viruses, and protists.
    (b) For each group, identify one characteristic that distinguishes it from the other groups.
    (c) Make a three-circle Venn diagram to display these data. (2.1, 2.2, 2.3) K/U T/I C A
71. Develop a menu for a meal that includes at least two foods prepared using prokaryotes and one food that is made from an organism in the kingdom Protista. Could the food item in **Figure 3** be included in such a meal? Explain. (2.1, 2.3) K/U A

Figure 3 Does ice cream contain any protist products?

Evaluation

72. Imagine that a few of the students in your school have carried out harmful pranks in the surrounding neighbourhood. A newspaper article about these pranks states that all of the students in your school are troublemakers. Explain why this is a good analogy for the perception many people have of bacteria. (2.1) T/I A

73. Your sister has taken a phone message from the veterinarian's office. She has written down that your dog's illness is caused by a halophile. Give two specific reasons why you know your sister has not recorded the phone message accurately. (2.1) T/I

74 A neighbour asks what you are studying in science class. She expresses surprise that you are studying bacteria. She mentions that this information is really only necessary for students going to medical school, who will need to understand human disease. Develop a polite way to point out the misconception your neighbour has about this topic and to justify the study of bacteria by all students. (2.1) T/I C

75 A scientist has proposed using the classification "semi-living" to describe viruses. Evaluate this scientist's proposal. Write a paragraph that expresses your support or lack of support for this classification. Include facts to justify your response. (2.2) T/I

76. Flash drives are a form of computer technology. They consist of a memory chip that can be plugged into the USB port of a computer. These portable devices are small enough that people often carry them on a key chain. The computer memory chip in a flash drive is usually encased in a protective cover, typically made of plastic. The information stored on a flash drive can be physically transported from one place to another, but the information cannot be read, manipulated, or copied unless the flash drive is plugged into the USB port of a computer. (2.2) K/U A
    (a) Identify and describe four specific ways in which bacteriophages are similar to flash drives.
    (b) Is a flash drive an effective analogy for a bacteriophage? Explain why or why not.

77. For several weeks, your friend has been suffering from a cold sore on her lip. When the sore healed, she stated that she was cured. (2.2) T/I A
    (a) Explain why your friend's statement is not accurate.
    (b) What is a more accurate explanation your friend could state?

78. As you wait in line to check out at the grocery store, you notice a magazine with the following headline: "Viral diseases are no longer a danger to humans; vaccines protect people from all viral disease." (2.2) K/U A
    (a) Identify and describe the error in this headline.
    (b) Rewrite the headline so it is more accurate.

79 Suppose that a family friend has decided to avoid all immunizations. She states that she is risking only her own health, so it should be her decision. Prepare a response to your friend's argument, emphasizing the risk to society of avoiding immunizations and the benefits to society of immunizations. (2.2) C A

80. A patient at a doctor's office describes symptoms that might be due to a viral infection or might be due to a bacterial infection. The doctor has run tests that will determine the cause of the symptoms, but it will take 24 h to get the results. The patient asks the doctor for antibiotics to take in the meantime, just in case it is a bacterial infection. The doctor refuses to prescribe the antibiotics until she has the test results. Write a paragraph that supports the doctor's caution in prescribing antibiotics. Your paragraph should include specific facts about bacteria. (2.2) T/I C

81. The word *malaria* is made up of the word parts *mal*, meaning "bad," and *aria*, meaning "air." The disease was named malaria because people believed that it was caused by foul or polluted air near latrines, swamps, and other stagnant water. (2.3) K/U A
    (a) Explain why the name *malaria* no longer reflects current scientific knowledge about the cause of the disease.
    (b) Imagine that you have been appointed to a committee assigned to develop an updated name for malaria. Suggest a new name for malaria. The name you suggest must reflect current scientific information about malaria.
    (c) Write an explanation that supports your suggested name.

82. Suppose you have been assigned to a student group that is asked to research and report on the Kingdom Protista. A member of the group suggests that the title of your presentation should be "A Typical Protist." (2.3) T/I C A
    (a) Explain why this is not a good title for the presentation.
    (b) Develop an alternative title for the presentation that would more accurately reflect the characteristics of the Kingdom Protista.

83. Evidence suggests that mitochondria and chloroplasts formed by the process of endosymbiosis. (2.3) K/U T/I A
    (a) Define the term "endosymbiosis."
    (b) Review the six pieces of evidence that support the theory of endosymbiosis of mitochondria and chloroplasts. Identify the one piece of evidence you find most convincing and explain your choice.
    (c) Draw a series of diagrams to illustrate the series of events that led to endosymbiosis.

Reflect on Your Learning

84. The bacteria cells found in and on your body outnumber the human cells that make up your body. These bacteria perform essential functions in the body, such as the production of vitamins. How does this statement affect how you think about your body? T/I C A

85. Vaccines have been described as one of the greatest achievements in medicine. Think about how your life might be different without vaccines. Then write a short explanation of how vaccines have affected your own life and the society in which you live. T/I C A

86. You have read about several areas of science in which a great amount of research remains to be done. Choose one of the following as an area of research you find interesting. T/I A C

- developing vaccines for viral diseases currently not preventable by vaccines, such as HIV/AIDS
- researching the role of protists in terrestrial ecosystems
- researching a more meaningful classification of organisms currently classified as protists

(a) Identify the area of research you personally find most interesting, and briefly explain why.

(b) Develop two specific questions related to this area that you would find interesting to research.

(c) Describe one possible benefit to society of increased knowledge in the area of research you have chosen.

87. You have read about the impact of increasing water temperature on aquatic protists. You have also read about the roles of aquatic protists in ecosystems. How does this information affect your thoughts about the importance of human actions that can slow or prevent global temperature increases? T/I C A

Research

GO TO NELSON SCIENCE

88. Some bacteria are genetically engineered to produce substances used for medical treatments, such as insulin. Make a diagram that gives an overview of how bacteria can be engineered to produce a specific substance. Prepare a short presentation in which you explain your diagram to the class. T/I C A

89. In agriculture, antibiotics are routinely added to animal feed. This practice has led to concerns about antibiotic resistance as well as the possible presence of antibiotics in food products made from animals. Research and prepare a written report on Ontario's regulations related to antibiotics in animal feed. T/I C A

90. Botulism is a serious disease caused by a bacterium. Humans can get botulism in several different ways, including through ingestion of foods containing the bacteria, which is an obligate anaerobe. Find out more about botulism, including the specific types of bacteria that cause it, the symptoms, and the three main ways that people can get botulism. Make a pamphlet to share what you have learned with the class. T/I C

91. Travellers to different parts of the world take precautions to avoid traveller's diarrhea, or "Montezuma's revenge." Research to find out what types of bacteria typically cause this disorder, precautions that can be taken when travelling to avoid this disorder, and areas of the world where travellers are most at risk. Write a paragraph summarizing what you have learned. T/I C

92. African sleeping sickness is a disease caused by a protist that is transmitted by a vector. Research African sleeping sickness to learn the following: the protist that causes African sleeping sickness, the organism that serves as the vector, the symptoms of the disease, and how the disease is treated. Prepare a one-page written summary of what you have learned. T/I C

93. Find out more about the uses and applications of diatomaceous earth. Choose one application to research in detail. Then share a brief description of what you have learned with your classmates. T/I C A

94. "Beaver fever," or giardiasis, is a disease caused by a protist that is of significant concern in Ontario. Find out measures that are taken to control this problem. Make a pamphlet to share what you have learned about ways that people can avoid this disease. T/I C A

95. Phosphates are substances that are used in detergents and cleaners. For many years, the amount of phosphates in products such as laundry soap and dishwashing detergent has been limited. Find out more about why the amount of phosphates in detergents is limited. Share what you have learned in a written paragraph. T/I C A

96. Kelp "forests" are highly productive marine ecosystems supported by photosynthetic brown algae. Research the relationship between these giant protists, sea urchins, and sea otters. How are these organisms interdependent? T/I

97. Species of *Plasmodium* have a very complex life cycle that includes an unusual form of cell division called schyzogony. Research this form of cell division. How does it differ from mitosis? How might this form of cell division benefit the organism? (2.3) T/I

CHAPTER 3

The Fungi, Plants, and Animals

KEY CONCEPTS

After completing this chapter you will be able to:

- describe key unifying and distinguishing features of organisms from the fungi, plant, and animal kingdoms
- explain how these kingdoms contribute to, and are dependent on, the biodiversity of life on Earth
- analyze some of the consequences of human influences and interactions on the biodiversity and health of ecosystems
- explain the significant changes that have occurred in fungi, plants, and animals as they have evolved over time
- make biological drawings of representative species

What Organisms Dominate the Land?

Life on land poses many challenges to living things. Unlike many aquatic environments, the conditions on land vary greatly. The most complex organisms—fungi, plants, and animals—have overcome these challenges and flourished. Most fungi and almost all plant species live in terrestrial ecosystems. And, although many animals are aquatic, the great majority of animal species are terrestrial.

In aquatic ecosystems, water temperatures are usually very stable. They may change by no more than a few degrees in a day and range from 20 °C to 0 °C in an entire year. In terrestrial ecosystems, temperature can change by 10 °C in 10 min and range from 40 °C to −40 °C in a year. Fungi, plants, and animals have responded to these variable conditions with adaptations that allow them to survive temperature fluctuations. Some organisms become dormant and others migrate. Some, including humans, spend extra energy to maintain a constant body temperature regardless of the surrounding environment.

Water is essential for all life but is not always available on land. Water loss through evaporation is a constant concern for terrestrial organisms. They deal with these challenges with waterproof coverings and internal water storage. Some plants even collect rainwater in cup-shaped leaves.

On land, organisms must be able to support their own mass against the force of gravity, without the buoyant force of water. To help them do so, they have developed supporting structures such as internal skeletons, external skeletons, and strong woody tissues. In animals, skeletons provide support and also allow mobility, including flight.

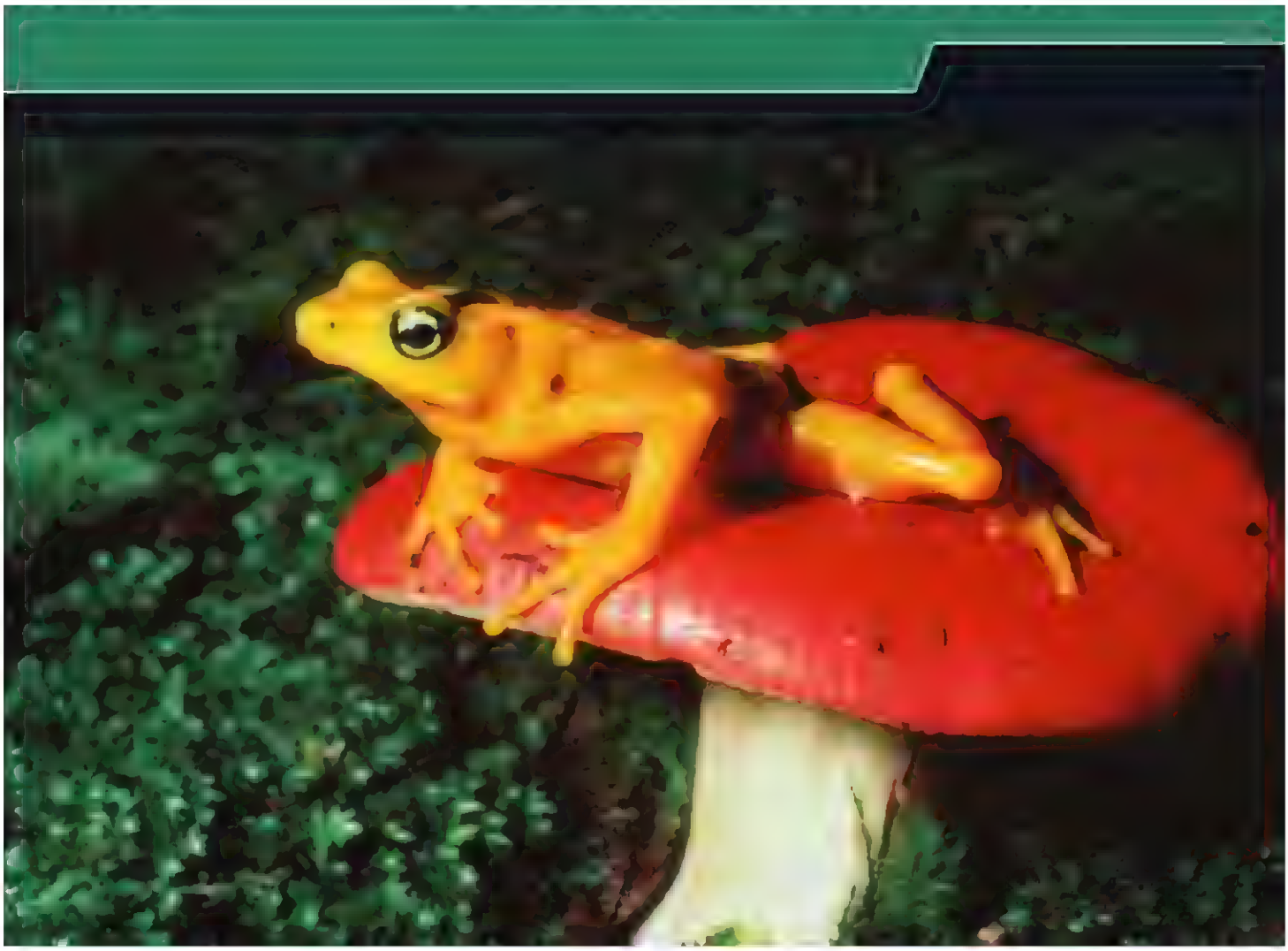
Fungi, plants, and animals also adapted to life on land with each other. They have established many relationships: producer and consumer, predator and prey, and symbiotic partnerships.

Humans, as members of the animal kingdom, share many of these adaptations and take part in many interrelationships with other species. Exploring the biodiversity of these three kingdoms offers us many insights into our own biology and the amazing web of life around us.

STARTING POINTS

Answer the following questions using your current knowledge. You will have a chance to revisit these questions later, applying concepts and skills from the chapter.

1. In what ways do you think the life cycles of organisms on land might be different from those in the water?
2. Some organisms are considered "simple," while others are considered "complex." What set of characteristics would you use to distinguish the simple from the complex?
3. The great diversity of life includes species that are adapted to very specific environmental conditions. How do you think changes to those environmental conditions due to climate change or pollution events, such as an oil spill, might impact species?
4. Brainstorm a number of human characteristics that make us well suited for life on land.



Mini Investigation

The Perfect Package

Skills: Questioning, Researching, Hypothesizing, Performing, Observing, Analyzing

SKILLS HANDBOOK A1.2, A2.1

Animal eggs and plant seeds are two key adaptations that enable animals and plants to flourish on land. In this activity you will examine a chicken egg and a coconut seed and consider how their features are well suited for life on land.

Equipment and Materials: eye protection; apron; beaker; hammer or mallet; tray or pie plate; chicken egg; coconut

1. Observe a chicken egg and a coconut. Describe their shape, colour, and texture.
2. Put on your eye protection and apron. Place the egg in the palm of one hand and evenly wrap your fingers around it. Slowly squeeze the egg, applying increasing pressure, until you think you are getting close to the breaking point of the egg.
3. Crack the eggshell open and put the egg into a beaker. Observe and describe all of the internal features and surfaces of the egg.
4. Place the coconut on a hard surface. Use a hammer or a mallet to carefully crack open the coconut. Place the contents on a tray. Observe and describe all of the internal features and surfaces of the coconut.

A. How well do these two biological "packages" protect the embryo inside? Were you surprised by their strength? T/I

B. A baby chick and a young plant shoot can both get out of their protective shells. How might the shape and features of these shells make this possible? T/I A

C. A developing embryo needs oxygen and nutrients. How are these provided by the egg and coconut? T/I A

3.1 The Fungi

Figure 1 Mushrooms are the most recognizable parts of fungi.

CAREER LINK

Arborist

Arborists diagnose and treat diseases in trees. To learn more about a career as an arborist,

GO TO NELSON SCIENCE

Fungi (singular: fungus) are some of the most common but least visible organisms on Earth. Fungi often grow out of sight — underground or within other organisms that may be either dead or alive. We are most familiar with the reproductive structures of fungi: mushrooms (**Figure 1**), toadstools, and mould spores. Although they were once thought to be plants, fungi actually have little in common with either plants or animals.

Why Fungi Are Important

Fungi have an enormous influence on ecosystems and economies. Along with bacteria, fungi are the major decomposers on Earth. Fungi are responsible for much of the cycling of nutrients through the biosphere. Fungi also engage in important symbiotic relationships with plants. As you will learn, almost all plants rely on fungi to help them obtain nutrients from soil. Without these fungi, plant growth and productivity would be severely reduced.

Not all fungi are helpful to other organisms. Fungi are responsible for some animal diseases and many serious plant diseases. These diseases can have a dramatic impact on natural plant populations and agricultural crops (**Figure 2(a)**). Every year, a staggering 10 % to 50 % of the world's fruit harvest is destroyed by fungi! Some valuable tree species have become nearly extinct because of fungi that were accidentally introduced into a region. Fungi also rot wood and damage buildings and other structures. Wood preservatives can prevent such damage, but they are toxic compounds that have their own environmental impacts.

Humans have many uses for fungi. Every time you eat mushrooms or their very expensive relatives—truffles—you are eating tasty fungi. Fungi are also used to make bread, soy sauce, and blue cheese (**Figure 2(b)**). The most economically valuable use of fungi is in the production of alcoholic beverages. Beer and wine are both multi-billion dollar industries that depend on fungi to ferment grains and grapes to produce alcohol. Non-food products we get from fungi include some extremely valuable "miracle drugs," including the antibiotic penicillin (**Figure 2(c)**) and the antirejection drug cyclosporine, which is used by organ transplant recipients. Certain fungi are also used in genetic engineering research and applications.

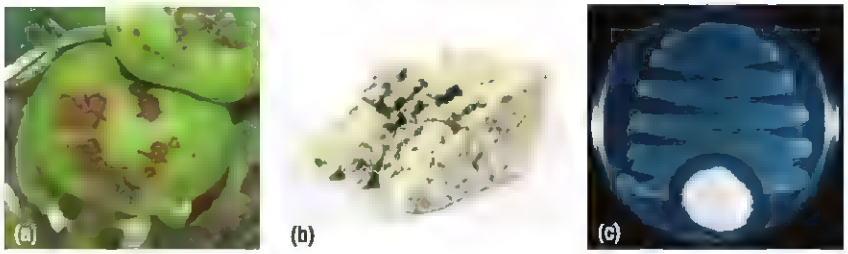


Figure 2 (a) Fungi cause some diseases in plants, such as apple scab. (b) Fungi are also used in the production of foods such as blue cheese. (c) Fungi are the source of one of our most important antibiotics—penicillin.

Classification and Phylogeny

Fungi are not plants. In fact, they have almost nothing in common with plants except that they are sessile (stationary) multicellular eukaryotes and many grow in the ground. Unlike plants, fungi are not photosynthetic, and they do not produce their own food. Their cells are unlike plant cells, and they have entirely different methods of reproducing. Despite these differences, many people think that fungi are plant-like. Even Linnaeus classified them as plants in his two-kingdom system.

We know now that fungi form their own clade, sharing a common ancestor from at least 400 million years ago. Although fungi are only distantly related to animals, they are actually more closely related to animals than they are to plants! (See Figure 6, Section 2.3, page 62.)

More than 100 000 species of fungi have been described. These are classified into five major phyla (**Figure 3**). The most recognizable are the Basidiomycota, which is the phylum containing most mushrooms, and the Zygomycota, which is the phylum containing many of the moulds found on fruits and bread. The five major phyla range in size from microscopic single-celled organisms to the largest organisms on Earth. They exhibit a diversity of forms and life cycles (**Table 1**).

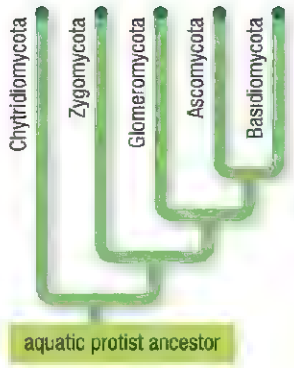


Figure 3 There are five major phyla within the Fungi kingdom. The Ascomycota and Basidiomycota phyla contain the most species.

Table 1 Summary of the Five Major Phyla of Fungi

Phylum	Key features
Chytridiomycota (chytr ds)	• They are the only fungi with swimming spores. • Most are saprophytes. • They can be single-celled or multicellular.
Zygomycota (zygomycetes)	• They include some familiar bread and fruit moulds. • Most are soil fungi. • Many are used commercially. • Many are parasites of insects.
Glomeromycota (glomeromycetes)	• All form symbiotic relationships with plant roots.
Ascomycota (ascomycetes)	• Many, such as yeast, are useful to humans. • Some cause serious plant diseases.
Basidiomycota (basidiomycetes)	• They include mushrooms, puffballs, and bracket fungi. • Most are decomposers. • Some form symbiotic relationships with plants.

LEARNING TIP

Some Moulds Are Protists
Organisms commonly referred to as slime moulds and water moulds were once thought to be fungi. Now they are recognized as a group of protists.

Characteristics

What we think of as a fungus is usually only one small part of the organism—the reproductive structure that usually grows out into the air. Most of the fungus—its "body"—remains hidden, often below ground. Fungi display an amazing diversity of characteristics and life cycles. For example, the bird's nest fungus has reproductive structures that look like bird's nests (**Figure 4(a)**). Each "egg" contains spores. Raindrops splashing into the "nest" push the eggs out of the nest and disperse the spores.

Cordyceps have familiar reproductive structures, but amazing life cycles. They are parasitic fungi of the phylum Ascomycota. They infect an insect host and change its behaviour, forcing it to climb to a high stem. The fungus then kills the host. Its reproductive structures grow through its body and release spores (**Figure 4(b)**). Because the spores are released from a high branch, they are dispersed widely.

Figure 4 (a) This bird's nest fungus belongs to the phylum Basidiomycota. (b) This *Cordyceps* fungus is growing through its host's body.

mycelium a branched mass of hyphae

hypha a thin filament that makes up the body of a fungus

chitin a complex chemical found in the cell walls of fungi and in the external coverings of insects and crustaceans such as lobsters and crabs

The bodies of most fungi are mesh-like, composed of a branching network of filaments called a **mycelium** (**Figure 5(a)**). These filaments are called **hyphae** (singular: hypha). Hyphae are often microscopically thin, and they have a structure unlike plant or animal cells. They consist of long tubes of cytoplasm containing many nuclei. The cytoplasm is contained by a cell wall made of **chitin**. The tubes may be separated into cell-like compartments by cell walls called septa (singular: septum). These septa are usually only partially complete, however, and contain large pores (**Figure 5(b)**). A key feature of hyphae is that the cytoplasm is continuous from end to end, allowing materials to move relatively quickly through the hyphae.

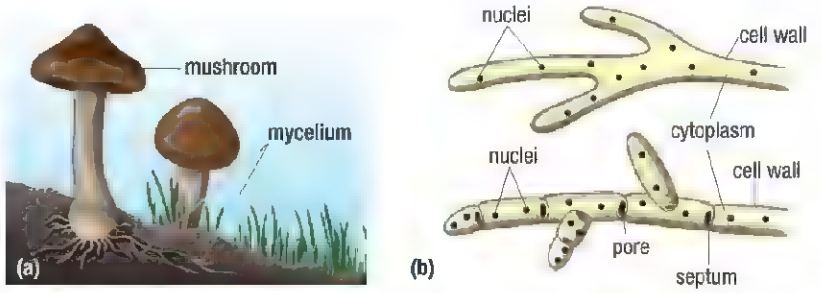


Figure 5 (a) The reproductive structure of a fungus is often the only part visible above ground. The mycelium forms the body of the fungus below ground. (b) Hyphae grow at their tips, and the nuclei multiply by mitosis as the hyphae grow.

Hyphae form the "fuzz" often associated with mould (**Figure 6(a)**). They also form the reproductive structures of many fungi. These structures take a wide variety of forms, including the puffballs shown in **Figure 6(b)**.

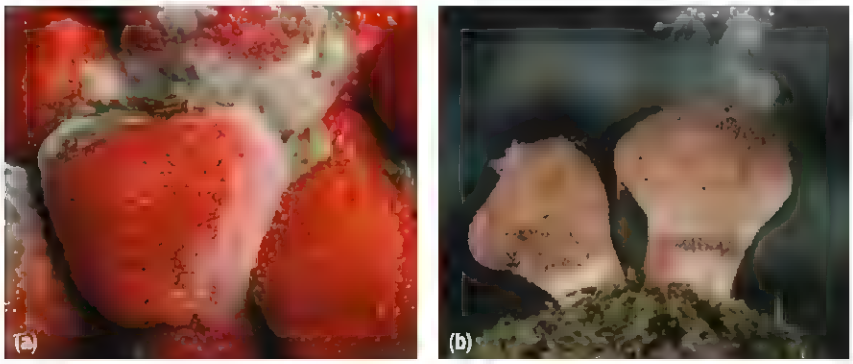


Figure 6 (a) The "fuzz" we associate with mouldy food is the hyphae of the fungus. (b) Even light contact with a mature puffball will cause the release of millions of microscopic spores.

LEARNING TIP

Zygote Formation
Zygotes normally form by the fusion of two different sex cells, such as a sperm and an egg. In fungi, zygotes can form from the fusion of two different nuclei within a single cell. This is still considered a form of sexual reproduction because each nucleus originated from a different individual.

Some fungi are single-celled. These fungi—called yeast—are very valuable economically because they are used in the production of many foods and alcoholic beverages.

One major difference between plants and fungi is that all fungi are heterotrophic—they get energy from other living or dead organisms. Fungi are different from most other heterotrophs, however, because they have external digestion. Rather than taking food inside their bodies, fungi grow next to—or within—their food source and release digestive enzymes into their surroundings. These enzymes digest the food, then the fungi simply absorb the nutrients through the cell membranes of the hyphae.

Life Cycles

The life cycles of many fungi are quite complicated. Some include stages of sexual as well as asexual reproduction.

The nuclei of most other eukaryotic organisms are diploid ($2n$), containing two sets of chromosomes. In fungi, most nuclei are haploid (n), containing only a single set of chromosomes.

Figure 7 shows the life cycle of a basidiomycete. Each spore (at left) contains a haploid nucleus. These spores germinate and produce hyphae with single nuclei separated by septa. When two hyphae come in contact with each other, two of their cells can fuse, forming a **dikaryotic** cell with two separate haploid nuclei. This cell then grows into a large new mycelium made of cells with two haploid nuclei. When the mycelium becomes large and mature, it may produce a mushroom cap. On the underside of the cap, spore producing structures called basidia form on the mushroom's gills. Within the basidia, the two haploid nuclei fuse, forming a zygote. This zygote then undergoes **meiosis**, producing four haploid spores. The spores are released into the environment. When conditions are right, these spores germinate and the cycle continues.

dikaryotic containing two separate nuclei

meiosis a form of cel. divis on in which a single cell gives rise to four haploid daughter cells

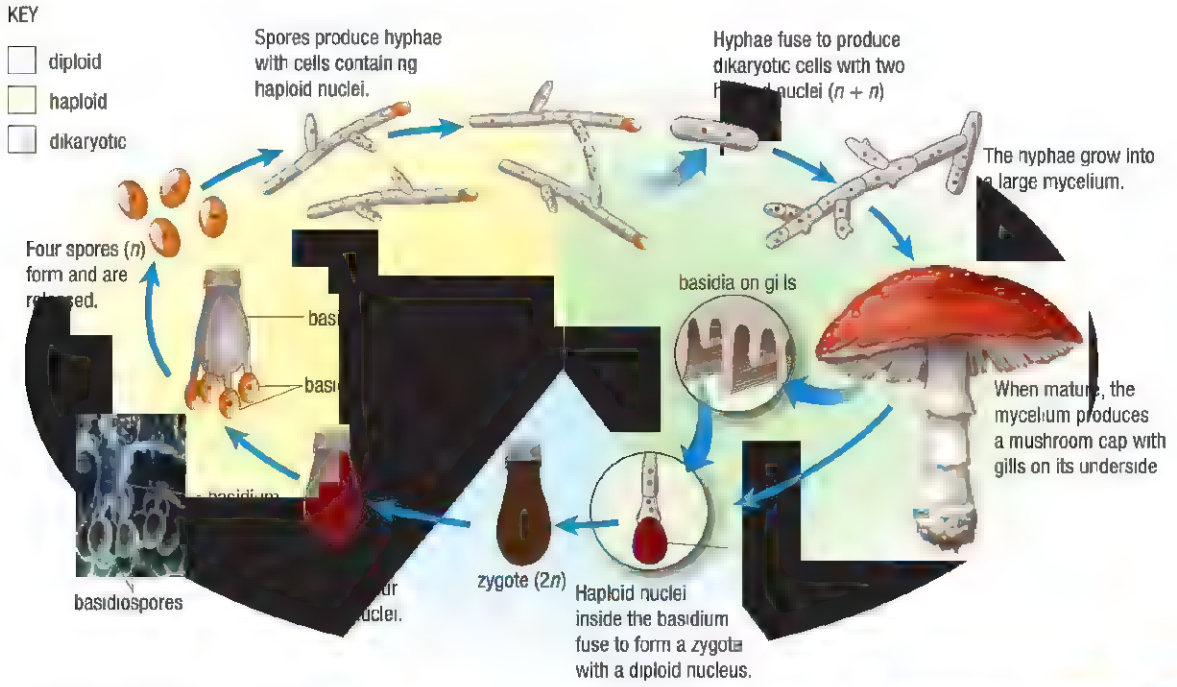


Figure 7 The life cycle of a basidiomycete

A single large mushroom can release 100 million spores in an hour! Such prolific spore production ensures that fungal spores are dispersed rapidly and widely. Any exposed surface is covered with fungal spores within seconds, and every breath you take contains many thousands of them.

Yeast are single-celled haploid fungi. They reproduce by budding. In budding, the individual yeast cell acts like a tiny hypha. The nucleus divides, and a septum forms between the two nuclei. This forms a small daughter cell on the side of the original yeast cell (**Figure 8**). As the cells continue to grow and bud, they often stay attached to each other, forming simple hypha-like arrangements. Yeast cells can also fuse and form a diploid cell that gives rise to four haploid spores, similar to the way in which multicellular fungi reproduce. Biologists consider this strong evidence that yeast evolved from multicellular fungi.

Figure 8 Yeast reproduce by budding.

Symbiotic Relationships in Ecosystems

You may have seen lichens—small crusty or pale moss-like organisms—growing on the exposed surfaces of bare rock or on the bark of trees. Lichens are symbiotic combinations of fungi and photosynthetic cyanobacteria or green algae (**Figure 9**).

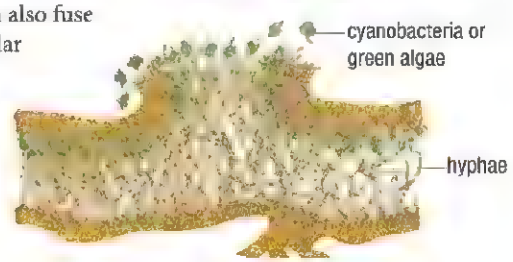


Figure 9 A cross-sectional diagram of a lichen showing the mixing of fungi (brown) and cyanobacteria or green algae (green).

Figure 10 Leaf-cutter ants were the world's first farmers. They use leaves to grow fungus in underground gardens.

mycorrhiza a symbiotic relationship between a fungus and a plant root

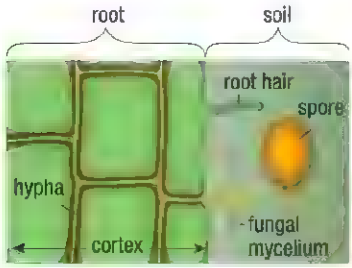


Figure 11 In mycorrhiza, a fungal mycelium grows in and around a plant's roots.

The fungi's mycelium envelops and protects the cyanobacteria or algae and supplies them with water and mineral nutrients. In return, these photosynthetic organisms supply the fungi with food. Lichens have an extraordinary ability to survive in harsh environments. They are often the first organisms to begin the process of ecological succession because they can grow on bare rock. Some lichens release chemicals that break down the rock and help form soil that can support plant growth.

Some fungi also have a fascinating symbiotic relationship with animals. Leaf cutter ants live in tropical rain forests in large colonies, some with millions of members. These ants cut and gather pieces of leaves, then bring them back to their colony (**Figure 10**). The ants are so numerous and so good at this task that they are the largest consumers of leaves in the forest. However, the ants do not feed on the pieces of leaf. Instead, they clean and chew the leaves into a pulp and use them to feed a fungus. The ants grow and tend these fungus gardens in underground chambers and feed almost exclusively on the fungus. Scientists have recently discovered how leaf cutter ants prevent other species of fungi from contaminating their fungus gardens: the ants have colonies of bacteria growing on their bodies. These bacteria produce chemicals that kill all other species of fungi.

Another symbiotic relationship involving soil fungi and plants has been uncovered over the past several decades. The most remarkable thing about this relationship is that more than 80 % of all plant species are involved! In this relationship, called **mycorrhiza** (plural: mycorrhizae), hyphae grow around or within the root cells of the plant. The fungi help supply the plant with needed nutrients such as phosphorus or copper (**Figure 11**). In return, the plant provides the fungi with energy rich food molecules.

Decomposers and Disease

Fungi that feed on living organisms cause a variety of human diseases, ranging from mild athlete's foot and ringworm infections to aspergillosis, a potentially deadly lung disease. Fungal diseases also affect many plants. Some of these diseases produce toxic chemicals as well as damaging the plants. One species of fungus that infects wheat and rye produces a potent toxin similar to the one found in the drug LSD. The toxin can cause hallucinations, convulsions, and paralysis. Another fungus that feeds on peanuts produces a chemical with the potential to cause cancer.

Research This

Fungi Threaten Plants and Animals

Skills: Researching, Analyzing, Communicating

SKILLS HANDBOOK A2.1, A5.1

In this activity you will research several very serious threats posed by the spread of fungal diseases.

1. Chytrid fungi infect many amphibians (**Figure 12**) Research the impact these fungi are having on frog populations around the world.

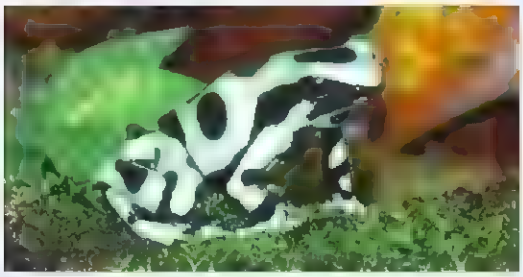


Figure 12 Many frog species, including this poison dart frog, *Dendrobates auratus*, are threatened by the spread of chytrid fungi.

2. Three tree species that were once very common in northeastern North America have been almost wiped out by Dutch Elm disease, Chestnut blight, and Butternut canker. All are fungal diseases introduced by humans. Research these diseases.

A. Why are scientists concerned about the spread of chytrid fungi? T/I

B. How and when was each fungus you researched in Step 2 introduced to North America? What tree species are affected by each fungus? How is each disease spread? T/I

C. What, if anything, is being done to stop the spread of these fungal diseases and protect the affected species? T/I

D. Prepare an information piece on one fungal disease you researched in this activity. Describe the current status of the threat and what people can do to help. You may choose to present the information in the form of a news video, radio announcement, brochure, or poster. T/I C

GO TO NELSON SCIENCE

3.1 Summary

- Most fungi are multicellular heterotrophs that use external digestion.
- The bodies of fungi consist of thin hyphae containing many nuclei, surrounded by a cell wall made of chitin. Fungi also have reproductive structures that produce spores.
- The life cycles of most fungi involve haploid individuals that reproduce both sexually and asexually.
- Most plant species depend on symbiotic relationships with soil fungi.
- Fungi are important decomposers that cycle nutrients in ecosystems.
- Fungi are extremely valuable economically, particularly in the production of breads, cheeses, and alcoholic beverages.
- Fungi cause many harmful crop diseases and some human diseases.
- The introduction of non-native fungi to ecosystems by humans has had serious environmental consequences.

Investigation 3.1.1

Growing and Observing Fungi (page 110)

Now that you have had a chance to read about fungi, you can complete Investigation 3.1.1.

In this controlled experiment you will design and conduct experiments to test factors that may influence the growth of bread mould.

3.1 Questions

1. Fungi were once placed in the same kingdom as plants. What evidence suggests that fungi are very different from plants? K/U
2. Make a simple labelled diagram of a hypha. Use your diagram to explain what is unusual about the cell structure of fungi. K/U C
3. Some fungi are considered predatory—they can capture and kill nematodes and other tiny soil organisms (**Figure 13**). Conduct research to determine how they do this. How is this activity related to the availability of nitrogen? K/U

Figure 13 Nematodes are tiny worms that live in soil.

4. In the absence of oxygen, yeast ferment sugar to obtain energy. This process releases carbon dioxide gas and ethanol (an alcohol). How do humans take advantage of this process in the manufacturing of foods and beverages? K/U
5. Describe the symbiotic relationships between fungi and leaf-cutter ants, and between fungi and cyanobacteria. K/U C
6. Many fungi decay wood. Use the Internet and other resources to research how "pressure-treated" technology works to prevent fungal attack. What chemicals are used and how are they applied to the wood? T/I
7. Wild mushrooms can be valuable and delicious, but eating the wrong mushroom can be deadly. Use the Internet and other resources to research which wild mushrooms are edible and most prized, and which are most dangerous. T/I
8. Human fungal infections cause athlete's foot, vaginitis, ringworm, and aspergillosis. Use the Internet and other resources to determine the specific causes of these infections, how they are spread, and how they are treated. T/I
9. Apple scab is a widespread fungal disease that attacks the leaves and fruits of apple trees.
   (a) Research apple scab disease and find out how it is controlled in Ontario.
   (b) Given a choice, would you rather eat an organically grown apple with the occasional scab that can easily be cut off, or a spotless apple that has been grown using a fungicide? Explain your reasoning. T/I
10. Since 2006 a mysterious and deadly disease has been spreading rapidly among many species of bats in northeastern North America. Infected bats exhibit a characteristic "white-nose syndrome" caused by a white fungus. Research the current status of this serious threat. How might the decimation of bat populations influence other species in these ecosystems? T/I A
11. The phylum Glomeromycota contains approximately 160 species. All these species form mycorrhizal relationships with plants. It is also known that more than 80 % of all plant species form mycorrhizal relationships with fungi. How do you think the loss of these fungi would affect the overall biodiversity of ecosystems? Explain your reasoning. K/U

GO TO NELSON SCIENCE

3.2 The Plants

Plants dominate most of the land on Earth. A small patch of forest contains thousands of trees (**Figure 1(a)**), while a golf course is covered in millions of individual grass plants (**Figure 1(b)**). Plants are ubiquitous in cities as well as in rural settings, indoors and outside. Even if you stay inside all day, you will almost certainly use plant products and eat a variety of plant foods (**Figure 1(c)**). Plants are so abundant that we may forget just how important they are.

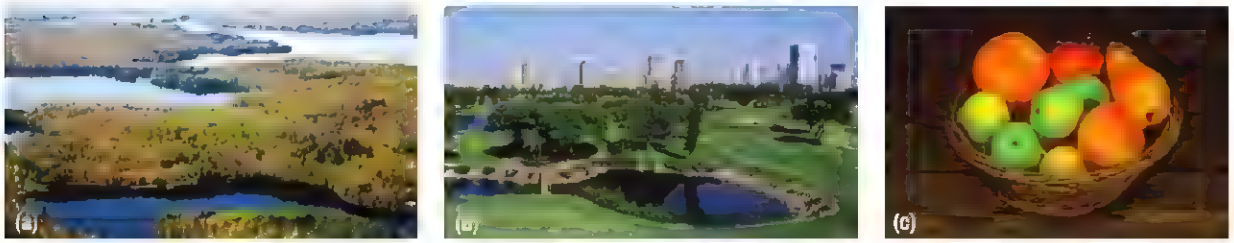


Figure 1 (a) From forests to (b) golf courses, much of Earth's surface is covered by plants. (c) Plants and plant products are all around us, in the products we use and the foods we eat.

Although we are surrounded and supported by ecosystems dominated by plants, most people know very little about them. But as you are about to learn, with more than 270 000 known species, plants are fascinating and incredibly diverse. The largest plants tower more than 100 m into the air, and the smallest are little more than a millimetre across. Today's oldest living tree has a root system that is over 9550 years old! This section gives an introduction to the characteristics and diversity of plants as well as an overview of how they adapted to life on land. The Plants unit provides a more detailed study of plant anatomy, growth, and function.

Why Plants Are Important

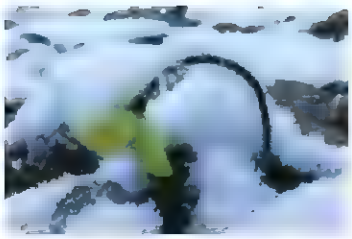


Figure 2 These Arctic poppies are found in Arctic and High Arctic climates, including Baffin Island.

Plants can survive in many different climatic conditions, from hot and humid tropics to parched deserts and the extreme cold of the High Arctic (**Figure 2**). Because plants are producers of food, other terrestrial life forms follow wherever plants live. In fact, the rich diversity of terrestrial ecosystems depends heavily on the diversity of plants. Without plants to supply food through photosynthesis, there would be little life on land.

In addition to supporting food webs, plants also provide other organisms with places to live, such as nesting locations for birds and supports for a spider's web. Humans are particularly dependent on plants for a wide range of valuable substances including medicines, clothing, wood, and paper products.

Unfortunately, many of the world's plants are threatened with extirpation or extinction. Habitat destruction, invasive species, pollution, and climate change all pose serious threats to plants and the organisms that depend on them. Today, 77 of Ontario's native plant species are listed as "species at risk." Of these, three species are extirpated—no longer living anywhere in the province.

Classification and Phylogeny

charophyte the common name for organisms in the order Charophyceae; green algae in the kingdom Protista

LEARNING TIP

"phyte"?
Many plant terms end with the suffix *–phyte*. *Phyte* is derived from the ancient Greek word *phut* (*ón*) meaning "plant."

Plants are thought to have evolved from **charophytes**, a group of green algae (which belong to the kingdom Protista), between 425 million and 490 million years ago. There is very strong evidence supporting this evolutionary relationship. Plants and green algae both contain chlorophyll *a* and chlorophyll *b*, two forms of the green pigment used in photosynthesis. They also contain pigments that are not found in other photosynthetic eukaryotes. Plants and green algae share several other characteristics. At the end of mitosis, only the cells of plants and green algae begin cytokinesis by building a cell plate across the middle of the cell. Their cell walls contain large amounts of cellulose, a complex sugar molecule. Plants and green algae also store excess food as starch.

Today there are more than 270 000 living species of plants. These are classified into four major groups. The phylogenetic tree in **Figure 3** shows the evolutionary relationships between the major groups of plants.

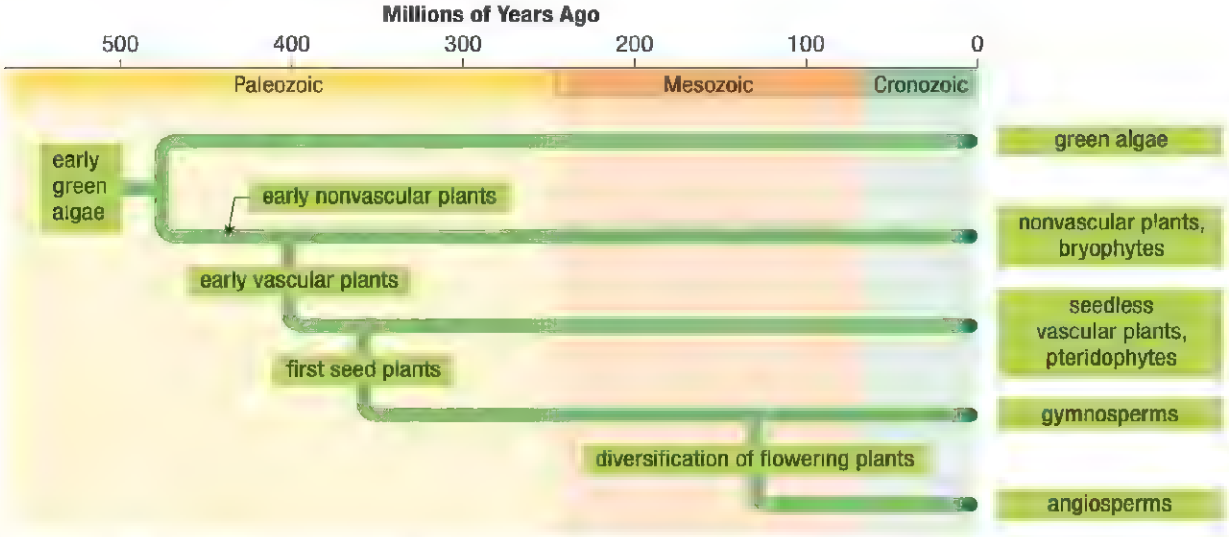


Figure 3 A simplified phylogenetic tree of the Plant Kingdom. Many biologists now include green algae within the Plant kingdom and refer to the other groups as the "higher plants."

Characteristics

All higher plants are multicellular eukaryotic organisms. Unlike animals and fungi, almost all plants perform photosynthesis. All have cell walls composed primarily of cellulose. Like fungi, all terrestrial plants are sessile—they cannot move from place to place. Although all plants share these basic features, plants show an incredible diversity of characteristics (**Figure 4**).

CAREER LINK

Botanist

Botanists specialize in the study of plants. To learn more about botanists,

GO TO NELSON SCIENCE

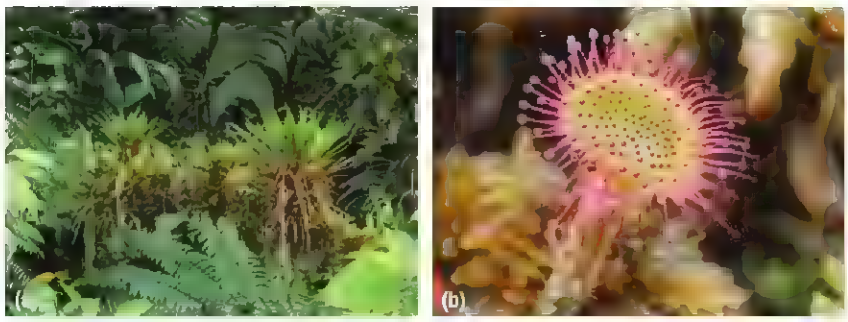


Figure 4 (a) In tropical rainforests, a great variety of plant species cover every square metre of available space, including the branches of trees. (b) Sundews are carnivorous plants native to Ontario bogs. Their leaf hairs secrete a sweet, sticky liquid that attracts and traps insect prey. These hairs and the leaf blade then slowly curl inward on the prey.

Alternation of Generations

Plants have a very different life cycle than that of animals. This life cycle is known as an "alternation of generations." This life cycle has diploid and haploid states, or generations. The diploid generation produces spores, and the haploid generation produces gametes.

UNIT TASK BOOKMARK

Compare and contrast the life cycles of the organisms in your chosen group. Do the conservation efforts aimed at this group need to take into account any features of this life cycle?

Typical animal body cells are diploid ($2n$), containing two sets of chromosomes. These cells undergo meiosis, producing haploid sex cells, or gametes. Two haploid (n) cells fuse in the process of fertilization, forming a diploid zygote that then grows into the adult animal **(Figure 5(a))**.

A plant in the diploid stage is called a sporophyte **(Figure 5(b))**. As in animals, the sporophyte's diploid cells divide by meiosis to produce haploid cells. In plants, however, these haploid cells form asexual spores. As the haploid generation begins, the spores grow into gametophyte individuals. The gametophytes mature, then produce haploid sex cells—gametes. These gametes undergo fertilization to form diploid zygotes. The zygotes grow into sporophyte individuals, and the cycle continues.

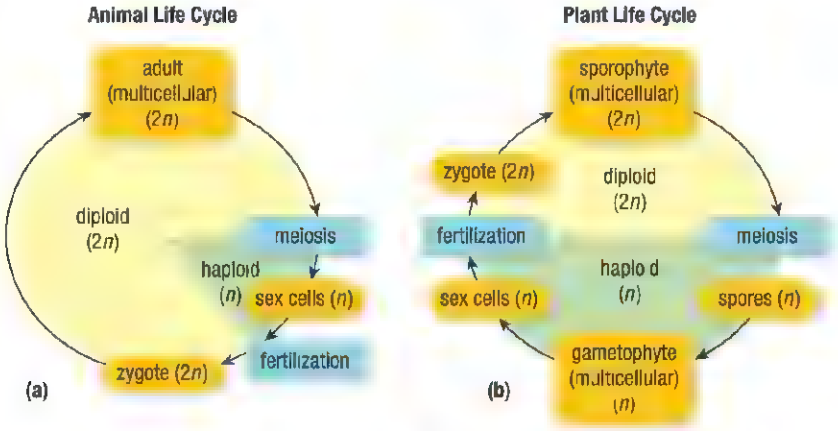


Figure 5 (a) A typical animal life cycle consists only of diploid individuals that produce haploid sex cells. (b) Plant life cycles alternate between a diploid sporophyte generation and a haploid gametophyte generation.

Research This

Climate Change and Plant Communities

Skills: Researching, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1, A5.1

Climate has a dramatic influence on the distribution and success of plant communities. Each plant species is ideally suited for a particular range of temperatures, water availability, and seasons. The greenhouse gases that humans release into the atmosphere are contributing to climate change. The main human-generated greenhouse gas is carbon dioxide—a key reactant in photosynthesis. In this activity you will research some of the ways in which the changing climate and increasing levels of atmospheric carbon dioxide are likely to affect plant distribution and diversity.

1. Use print and online resources to research the following topics:
   (i) How might an earlier spring and later fall influence plants?
   (ii) Explain how climate change is causing Ontario's plant communities to move northward.
   (iii) What effects could a changing climate have on plant pests and disease? On forest fires?
   (iv) How are increasing concentrations of carbon dioxide in the atmosphere likely to influence plants?

A. Based on your research, how will climate change and increasing levels of carbon dioxide in the atmosphere likely affect plant distribution? T/I

B. How will climate change and the resulting changes in plant distribution affect biodiversity? Consider the effects on the biodiversity of plants as well as the ecosystems and food webs they support. T/I A

GO TO NELSON SCIENCE

Early Adaptations for Life on Land

Most plant species living today live on the land. There are some aquatic species, but most are freshwater—only a few are marine. The primitive ancestors of today's plants, however, lived in the water. They were probably very much like green

algae—relatively small, photosynthetic, multicellular organisms. These early plants, like green algae living today, would have reproduced sexually using eggs and sperm that swam through the water.

When plants first began to live on land, they developed characteristics that allowed them to live and reproduce in that new environment. Although life on land gave plants lots of light and carbon dioxide—both essential for photosynthesis—it forced plants to adapt in other ways.

The first requirement for life on land was the ability to prevent water loss. When exposed to dry air and warm temperatures, unprotected living cells quickly lose water through osmosis and evaporation. Plants developed a flexible, waxy **cuticle** on their outer surfaces that effectively prevents water loss (**Figure 6(a)**).

cuticle a waterproof, waxy coating produced by the epidermis of most plants

Although preventing water loss is critical for land plants, they must be able to take in small amounts of carbon dioxide gas from the atmosphere in order to perform photosynthesis. To meet this need, plants developed **stomata** (singular: stoma), tiny openings between specialized cells on the plant's surface (**Figure 6(b)**). These stomata are like windows that can be opened and closed. When they are open, gases can diffuse into and out of the plant. When they are closed, the plant is effectively sealed off from the surrounding air.

stoma a small opening in the epidermis of a plant that allows gas exchange

Figure 6 (a) Almost all plant surfaces produce a waterproof, waxy cuticle. (b) Stomata are small openings in the epidermis that allow gas exchange with the air. Most leaves have thousands of stomata per square centimetre.

Bryophytes: The Mosses

The **bryophytes** are the simplest of land plants. This group includes the mosses, liverworts, and hornworts. The most recognizable of these are the mosses—there are more than 1000 species of moss in North America alone! The peat mosses, of the genus *Sphagnum*, may be the most numerous plants on Earth. In many ecosystems, including Canada's boreal forest, *Sphagnum* mosses can form a continuous ground cover over hundreds and thousands of square kilometres (**Figure 7**).

bryophyte a small seedless plant that lacks vascular tissue

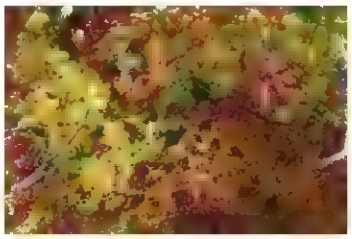


Figure 7 Various species of sphagnum moss form a thick covering in this bog.

Like the earliest of land plants, bryophytes have a protective cuticle and stomata for gas exchange. They do not have specialized vascular tissue or true leaves, roots, or seeds. Most bryophytes are only a few centimetres in height.

The gametophyte generations of bryophytes produce swimming sperm in structures called **antheridia** (singular: antheridium) and eggs (in structures called **archegonia** (singular: archegonium). Bryophytes can therefore only live and reproduce in places with at least occasional wet conditions, such as rains or heavy dew.

antheridium the specialized structure on a gametophyte that produces sperm

archegonium the specialized structure on a gametophyte that produces eggs

The green plants we recognize as mosses are the photosynthetic gametophyte individuals. After fertilization, the new, non-photosynthetic sporophyte individuals grow out of the archegonia on the female gametophyte and get their nourishment from the gametophyte. These sporophytes seem to be part of the gametophyte but are actually the offspring of the gametophyte plants. The sporophytes grow a tall stalk that bears a structure called a **sporangium** (plural: sporangia), in which haploid spores are produced. These tiny spores are easily carried by winds and dispersed over a large area.

sporangium the structure in which spores are produced

gemma a small clump of haploid photosynthetic cells produced in little cup-shaped structures on the gametophyte plant, dispersed by splashes of rain to grow into another gametophyte plant

Figure 8 illustrates the alternation of generations life cycle of a typical moss. Some moss gametophytes can also reproduce asexually. Small clumps of photosynthetic haploid cells called **gemmae** (singular: gemma) are produced in cup-shaped structures on the surface of the gametophytes. The gemmae are dispersed by splashes of rain and grow into new gametophyes.

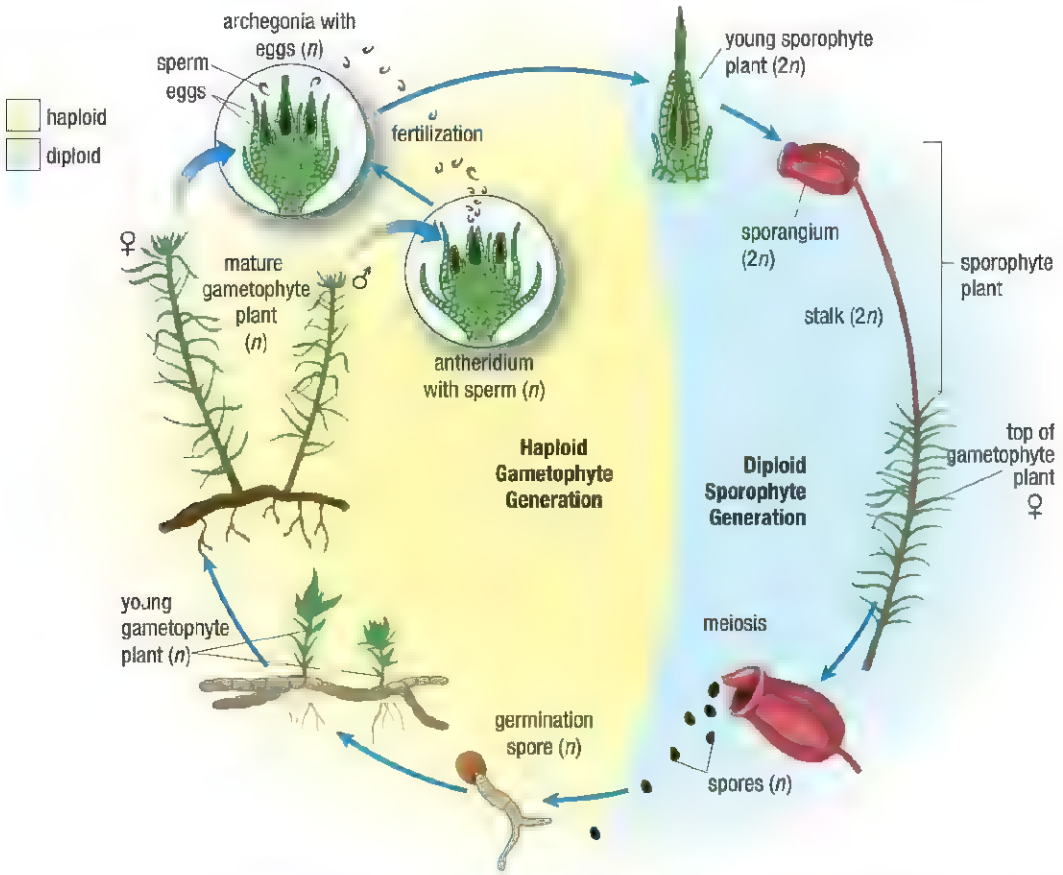


Figure 8 The life cycle of a moss. In order to fertilize the eggs, sperm must swim through water on the surface of the gametophytes.

Lycophytes and Pterophytes: The Ferns

The next major adaptation by land plants was the development of vascular tissue. Vascular tissue consists of xylem and phloem. It is specialized for the transportation of water and nutrients. Plants with vascular tissue can grow to great heights, thereby accessing more sunlight. **Lignin** is a key chemical component of vascular tissue. It is an extremely strong compound that makes cell walls more rigid. It is responsible for the great strength of woody tissues.

lignin an important structural compound found in the vascular tissues of plants; it is responsible for the strength of wood

lycophyte a seedless vascular plant; club mosses are examples of lycophytes

pterophyte a seedless vascular plant; ferns are examples of pterophytes

The **lycophytes** (club mosses) and **pterophytes** (ferns and their relatives) are groups of seedless vascular plants that still have many characteristics of the earliest vascular plants. During the Carboniferous period, about 360 million to 300 million years ago, these plants dominated the landscape. Some grew as large as 2 m in diameter and more than 40 m in height! Today's 13 000 or so species remain widespread and common, but most are relatively small.

Among the simplest of vascular plants are members of the genus *Equisetum* called horsetails. They are considered "living fossils" because they are the only remaining genus of what was once a very diverse group of plants. As they grow, silica crystals form on their stems.

Similar to bryophytes, the gametophyte individuals of lycophytes and pterophytes reproduce sexually using sperm and eggs. Unlike the bryophytes, however, the sporophytes are photosynthetic and much larger than the gametophytes (**Figure 9**). Both groups have simple roots and stems. The stems of ferns are usually in the form of **rhizomes** that grow horizontally just below the surface of the ground. Ferns also have large green leaves called **fronds**.

rhizome a horizontal underground stem

frond a fern leaf; young curled fronds are often called "fiddleheads" because of their distinctive shape, some fiddleheads are edible, but many are toxic

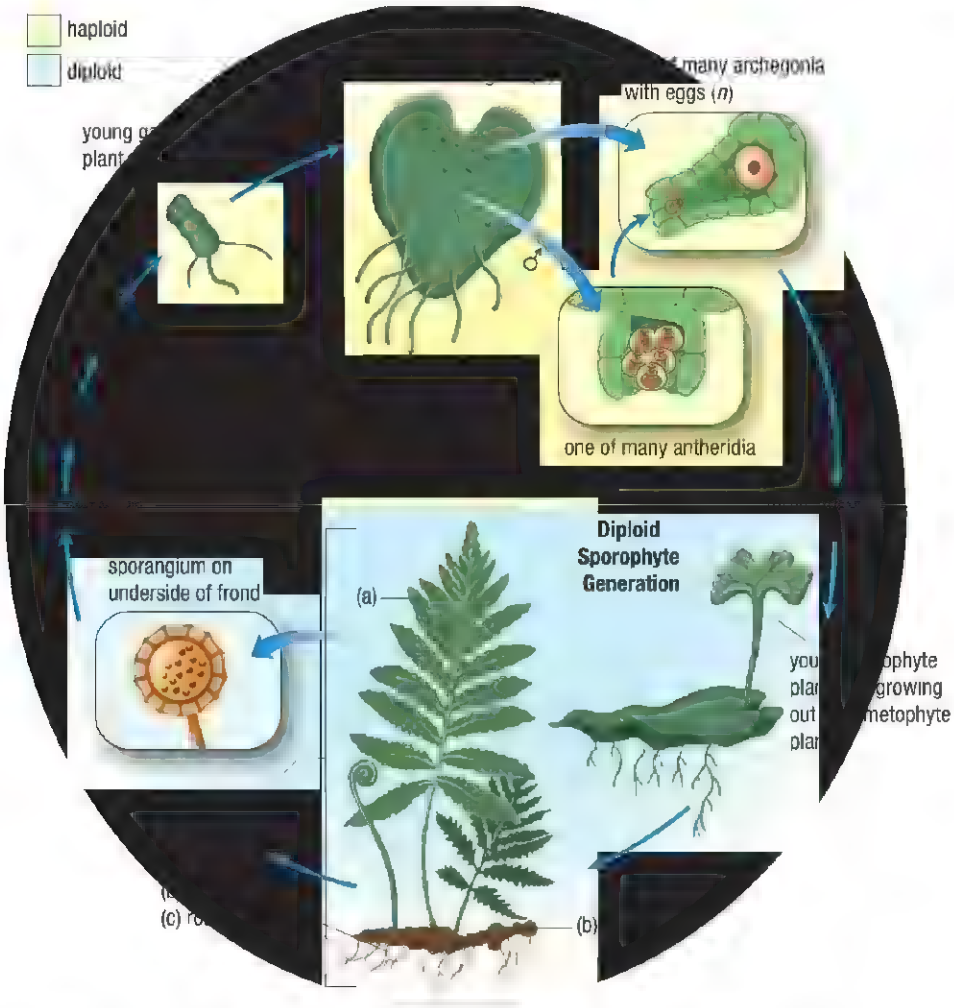


Figure 9 Life cycle of a fern. Note that the sporophyte is photosynthetic and much larger than the gametophyte. The gametophyte (less than 1 cm across) is greatly enlarged in this diagram.

In addition to simple roots, many lycophytes and pterophytes have also developed symbiotic mycorrhizal relationships that help them obtain water and other nutrients from the soil. In fact, the gametophytes of lycophytes are non-photosynthetic and live hidden underground, where they get nutrients directly from symbiotic fungi.

Gymnosperms and Angiosperms: The Seed Plants

Today almost all lycophytes and pterophytes grow in the shadows of seed plants. In most of these plants, the entire male gametophyte is carried from one plant to another by the wind or by animals, instead of travelling through water. Seed plants are therefore not restricted to reproduction over short distances in wet conditions, and they have become the dominant land plants on Earth.

pollen small structures called "grains" that contain a microscopic haploid male gametophyte

ovule a small structure that contains a microscopic haploid female gametophyte

seed a plant structure containing an embryo and a food supply, surrounded by a protective outer covering called the seed coat

Pollen grains are waterproof capsules that contain microscopic haploid male gametophytes (**Figure 10(a)**). Pollination occurs when the male gamete in a pollen grain penetrates an **ovule** containing a female gametophyte. The male gamete fertilizes the egg, producing a diploid zygote. This diploid zygote, or embryo, becomes a **seed**.

Seeds contain a food supply for the embryo inside a seed coat (**Figure 10(b)**). They vary dramatically in size from the gigantic seeds of the Coco de Mar, or sea coconut, with a mass of more than 17 kg, to the microscopic seeds of certain orchids, with a mass of less than 0.001 g! Seeds can remain dormant, allowing the embryo to survive for extended periods of time until conditions are suitable for it to germinate.

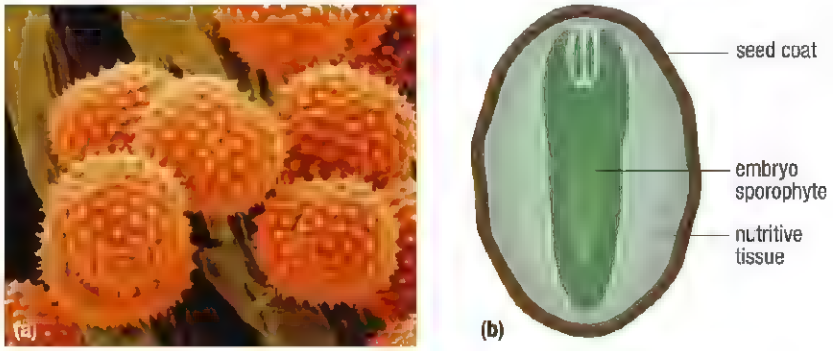


Figure 10 (a) Pollen grains are microscopic and have variable shapes and surface features. (b) Seeds contain a young sporophyte embryo, a nutrient-rich tissue and an outer protective coating.

The food supply within the seed provides the young plant embryo with the nutrients it needs to grow a small root, a stem, and leaves before it is able to rely on photosynthesis. This food supply is a concentrated mix of starch, plant oils, and some protein. It is therefore a very important food source for many animals—including humans. More than 70 % of all human food supplies are derived from the seeds of just three plants: wheat, rice, and corn.

You will study the life cycles, structure, and functions of seed plants in much greater detail in the Plants unit. What follows now is an introduction to the most important members of the Plant kingdom.

gymnosperm a vascular plant that produces seeds in special structures called cones; gymnosperms are a major plant group

cone in plants, the reproductive structure of a conifer; produce either pollen or ovules

Gymnosperms: The Conifers

Gymnosperms include the coniferous trees such as pines, spruce, cedars, and junipers, and other less well known groups of plants including the cycads and ginkgoes.

Cones are the reproductive structures of conifers. Male cones produce and release pollen, and female cones produce eggs. When an egg is successfully pollinated and fertilized within a female cone, an embryo develops within a seed in the cone.

There are about 800 species of modern gymnosperms. Many of these are woody trees, and most have needle- or scale like leaves. These narrow leaves and their thick cuticles are adaptations that help the trees reduce water loss. Gymnosperms have large, shallow root systems that form a mycorrhizal relationship with symbiotic fungi (**Figure 11**). Many gymnosperms are well adapted to resist hot dry summers and cold winters.

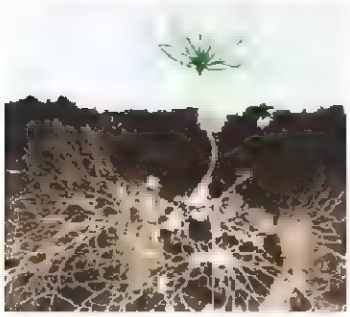


Figure 11 This cross-section shows the mycelium of the fungus extending far beyond the root system of the seedling.

Gymnosperms are very valuable. They provide about 85 % of all wood used in construction and furniture manufacturing and are also the source of almost all pulp and paper.

Some gymnosperms are gigantic. The largest single conifer on Earth is in California. This giant sequoia named "General Sherman" is 83 m tall and has a circumference at its base of 33 m. Its estimated mass of 1400 tonnes is equivalent to the mass of about 10 000 average-sized adult humans! This single tree contains enough lumber to build more than 100 average-sized homes.

The boreal forests of northern Ontario are dominated by spruce trees and are a major source of lumber and pulp and paper. They also support many large ecosystems—they are home to many species of wildlife. Some gymnosperms can live for hundreds of years and are the foundation of well-established and complex ecosystems. For example, the Three Sisters (**Figure 12**) live in Carmanah Walbran Provincial Park in Vancouver, British Columbia. They are three Sitka spruces that share a root system. These 80 m tall trees are part of an ecosystem that is hundreds of years old!

Threats to the boreal forest, including from climate change and harvesting practices, have raised some serious concerns about future sustainability. In May 2007 more than 1500 scientists from around the world endorsed a document called the Canadian Boreal Forest Conservation Framework. Continued efforts have since led to a truly remarkable agreement between the Forest Products Association of Canada and nine leading environmental organizations. In May 2010 these organizations signed what is considered the largest forest conservation plan in history. The plan calls for strict environmental safeguards for 700 000 km^2 of boreal forest, including 300 000 km^2 where cutting will be halted to protect threatened woodland caribou.

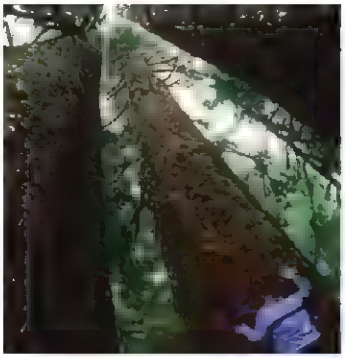


Figure 12 The Three Sisters

Research This

Plant Conservation Initiatives

Skills: Researching, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1, A5.1

Biodiversity is seriously at risk in most parts of the world, including Canada. Close to one-third of all vascular plants are threatened with extinction within 30 years unless action is taken soon to protect them. Canada is home to more than 3000 species of native vascular plants. About 1000 of these have been classified as rare by the Canadian Museum of Nature. Scientists, government and non-profit agencies and institutions, and members of the public are all involved in taking action to conserve biodiversity in their region and elsewhere. In this activity you will research a specific conservation initiative aimed at protecting a particular plant or plant community

1. Research several public and private conservation agencies and organizations involved in plant conservation. Consider international and regional environmental organizations and botanical gardens. Choose one program or initiative that you believe is important.
2. Investigate the program in detail and report back on the following aspects of the program:
   (a) What plant or plant community is the program designed to protect? Why was this particular plant or plant community considered in need of protection?
   (b) What are the benefits of protecting this plant or plant community?
   (c) What are the specific goals of the program? How are they being put into action?
   (d) Who funds or financially supports the program?

A. Do you believe the program is worthwhile? Is it likely to be successful in the long term? Why or why not? TPI

B. Write a 30-s radio ad that describes and promotes the program. Share your ad with the class. C

GO TO NELSON SCIENCE

Angiosperms: The Flowering Plants

More than 90 % of all modern plant species are **angiosperms**, or flowering plants. The more than 260 000 species of angiosperms dominate the modern world of plants. With the exception of coniferous trees, mosses, and ferns, virtually all familiar trees, shrubs, and herbaceous plants are angiosperms.

As their common name suggests, angiosperms have specialized reproductive structures called flowers. **Flowers** perform the same function as cones in producing both pollen and eggs. However, in female flower parts, the eggs are protected in an enclosed ovary. After fertilization, seeds form within the ovary and the outer tissues of the ovary become a **fruit**. The main function of the fruit is to help disperse the seeds. The development of flowers and fruits is key to the success of the angiosperms.

There are two types of seeds in angiosperms. Each seed contains either one ("mono") or two ("di") cotyledons. **Cotyledons** are structures that store food used by the growing embryo during germination.

angiosperm a plant that produces flowers; angiosperms form the largest group of living plants

flower the specialized reproductive structure of an angiosperm; produces pollen and/or ovules

fruit the mature ovary (or ovaries) of flowering plants that contain seeds; fruit help protect and disperse seeds

cotyledon a structure in the seeds of flowering plants that stores nutrients

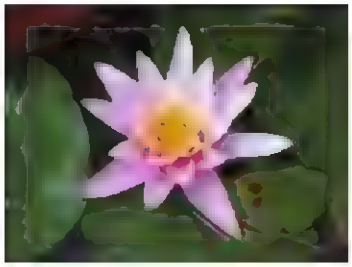


Figure 13 Water lilies be ong to a small group of flowering plants called Nymphaeales.

The two largest groups of flowering plants are the monocots and the eudicots. The monocots, comprising some 60 000 species, include more than 10 000 species of grasses and 20 000 species of orchids. The eudicots, with more than 200 000 species, account for most of the rest. Almost all flowering trees are eudicots. There are a number of smaller groups that do not belong to either the eudicots or monocots. These plants, which include magnolias, cinnamon, black pepper, and water lilies (**Figure 13**), also have seeds with two cotyledons.

Flowers are extremely diverse (**Figure 14(a)** to **(d)**). These structures are specialized for the way the plant is pollinated. Many flowering plants are wind pollinated. The flowers on such plants are typically small and drab looking. Examples include the flowers of grasses. Other flowers are pollinated by animals such as bees, bats, and hummingbirds. These are often colourful and fragrant and produce nectar. These special features attract and reward pollinating animals. By carrying pollen from one plant to another, animal pollinators enable plants of the same species to engage in sexual reproduction.

Fruits are equally diverse (**Figure 14(e)** to **(h)**). Each fruit is adapted to protect and disperse the seeds within it. Dispersal methods include using wind, water, and other organisms. These adaptations help ensure that the plant reproduces successfully.

Figure 14 Flowers and fruits reflect the great diversity of the flowering plants. (a) Irises, (b) forget-me-nots, (c) yellow lady's-slippers, and (d) leatherleafs are all pollinated by animals. (e) Some fruits stick to animals, such as burdock, (f) some are eaten by animals, such as these twisted stalk berries, (g) some float in the air, such as this goat's beard, and (h) some float in the water, like these coconuts.

Mini Investigation

Observing Plant Diversity

Skills: Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK A1.2, A2.1, A3

Plants are a large and diverse group of organisms. In this investigation you will examine two or more plant specimens and note their key distinguishing features. You will classify each into one of the major groups of plants described in this section and make labelled biological drawings of the plants.

Equipment and Materials: hand lens or dissecting microscope; 2 or more plant samples

1. Carefully examine each plant, noting any distinguishing features. Consider whether you are examining a gametophyte or sporophyte specimen.
2. Use the features you observed to classify each plant into one of the major plant groups.
3. Make labelled biological drawings of each plant.

A. How did you determine whether your specimens were gametophytes or sporophytes? TI

B. To what major plant groups do your specimens belong? What features did you use to classify your specimens? TI C

C. Which key adaptations do these plants have for life on land? TI

D. Use the Internet to find out more about your plant specimens. What type of environment do they live in? TI

GO TO NELSON SCIENCE

Conquering the Land

When plants colonized land more than 400 million years ago, it was one of the most dramatic events in the history of life on Earth. It created a diversity of living habitats and food sources for countless terrestrial animals, including you. Unfortunately this diversity is threatened by human actions. The most widespread threat is climate change, which has the potential to affect plants living everywhere on Earth. Overharvesting plants threatens many species, including Ontario's goldenseal, wild ginseng, and prickly pear cactus. Some plants are also particularly sensitive to various forms of pollution. For example, ground-level ozone—a major pollutant of urban environments—interferes with photosynthesis in some plant species.

UNIT TASK BOOKMARK

As you work on the Unit Task, consider threats to plants and other organisms that support your chosen group. Are any conservation efforts being taken to conserve the ecosystems the group is part of?

3.2 Summary

- Plants are large, multicellular eukaryotes that evolved from a group of green algae more than 400 million years ago.
- As producers, plants support virtually all terrestrial food webs.
- Plant life cycles alternate between haploid and diploid generations.
- Bryophytes are simple plants with a waxy cuticle and stomata to reduce water loss and allow gas exchange.
- Ferns are seedless vascular plants with large leaves and simple roots.
- Gymnosperms are seed plants that reproduce with specialized cones that produce pollen grains and ovules.
- Angiosperms are the most diverse group of plants and reproduce using flowers. Angiosperms produce seeds within a specialized structure called a fruit.
- Flowering plants provide most of the food consumed by humans and our domesticated animals. The three most important food crops are wheat, rice, and corn. All are monocot grasses.
- Plants are threatened by a number of human actions, and by climate change.

3.2 Questions

1. Rev ew the evidence that links plants to charophytes. K/U
   (a) List features shared by plants and charophytes that are not shared with most other eukaryotes.
   (b) Based on your understanding of endosymb osis and the evolution of eukaryotes, would you expect any photosynthetic bacteria to share the same pigments as charophytes and plants?
2. Explain how each of the following adaptations dramatically enhanced the success of land plants: K/U C
   (a) vascular tissue
   (b) animal pol ination
   (c) pollen grains
   (d) seeds
   (e) fruit
   (f) mycorrhiza
3. Make a table with check marks to indicate which of the adaptations from Question 2 occurs in the following groups of plants. List the adaptations down the side and the plant groups across the top. K/U C
   (a) mosses
   (b) ferns
   (c) conifers
   (d) flowering plants
4. Consider the sporophytes and gametophytes of mosses and ferns: K/U C
   (a) In which group(s) does the sporopnyte become independent and photosynthetic?
   (b) Which forms require liquid water in order to reproduce?
   (c) Which are able to spread farther, their spores or their gametes? Explain.
5. Why are seeds a particularly valuable source of food for humans and other animals? K/U
6. Many colourful flowers reward animal pollinators with a supply of sweet nectar. This encourages animals to visit the flowers and, in so doing, carry pollen from one flower to another. Many fruits, containing the seeds of the plant, are also colourful and sweet. Brainstorm the possible benefit(s) to the plant when animals feed on these fruits. A
7. A group of 34 regions on Earth, referred to as biod versity hotspots, contain more than half of al. plant species but cover only 2.3 % of Earth's and area. Use the Internet and other resources to find out more about these special places. Choose one hotspot and find out where it is located and what types of plants and animals live there. Report your findings to the class. T/I C

GO TO NELSON SCIENCE

3.3 The Animals

Animals are the most complex of all organisms (**Figure 1**). They are multicellular eukaryotes. Unlike plants and fungi, most animals are motile (they can move around), have amazing sensory ability, and are capable of very complex behaviours. These traits, along with a myriad of shapes, sizes, and ecological roles, create a truly remarkable kingdom, of which you are a member!

In this section we will focus on some particularly important and representative groups of animals. You will also study animals, with an emphasis on humans, in more detail in the Animals unit.

Figure 1 (a) The body structure of a sea slug, (b) the sensory ability of a damsel fly, (c) the ecological niche of a shield spider, and (d) the complex social behaviour of these lemurs hint at the incredible diversity within the Animal kingdom.

Mini Investigation

Observe Animals on the Move

Skills: Questioning, Researching, Observing, Analyzing

SKILLS HANDBOOK A1.2

Many animals have extraordinary sensory abilities. They can hear, see, taste, smell, and touch. Some animals can even detect electrical and magnetic fields. These senses provide detailed information about the surrounding environment. Animals use this information to respond through physical action—animals move! In this investigation, you will observe animals moving and responding to the environment.

Equipment and Materials: 1 or more live animal specimens such as aquarium fish, snails, ants, pill bugs, or earthworms and suitable enclosures; hand lens; small paintbrush; ruler; stopwatch

1. Spend 10 uninterrupted minutes carefully observing the movements of an animal. Note the subtle motions of legs, fins, gills, eyes, antennae, mouth parts, or other body parts that you can see moving.
2. Note how the movement takes place. For example, if the animal has legs or fins, describe the coordination of their movements. If the animal does not have limbs, how does it move?
3. If possible, measure the speed of the animal's movements.
4. Note any apparent purpose for the animal's motions. For example, are there rhythmic motions that might be associated with breathing, or do the motions seem to occur in response to some outside stimulus?
5. Slowly approach the animal with the paintbrush and observe how it responds. If the animal does not move away, you may make gentle contact with the surface of the animal. Record any response. Do **not** frighten or injure the animal.
6. Consider introducing other stimuli such as food, water, or a light source to test the animal's response.

A. Which body parts appear to be coordinated? Describe any specific patterns that you observed. T/I C

B. Describe evidence of your animal's ability to detect changes in the environment. T/I

C. Use the Internet and other sources to view videos of octopus and starfish. Describe the ways in which they move T/I A

GO TO NELSON SCIENCE

Why Animals Are Important

Humans have a special interest in animals—after all, we are animals too! The more we learn about the biology of animals, the more we learn about ourselves. As we improve our understanding of animal biology, we also improve our understanding of the origin and cause of human diseases and how best to keep our bodies and minds healthy.

We also depend on many other animal species for our own survival. We use many species of wild and domesticated animals as sources of food and other products. We depend on animals to pollinate important food crops, and we count on animals to play their important roles in maintaining the health of natural ecosystems. Humans also have a special affinity for their pets. Many people describe their pets as being part of their family.

But our interests in biology reach beyond finding out how other species benefit humans. Humans have always been fascinated by the remarkable diversity and characteristics of animals. Throughout history and across cultures, animals have been revered as symbols of power, beauty, freedom, and even peace. This admiration is shown in our deep concern for, and great efforts to protect, many endangered animal species, including giant pandas, elephants, rhinoceroses, polar bears, and Canada's peregrine falcons (**Figure 2**).

Figure 2 Capable of reaching speeds in excess of 300 km/h, the peregrine falcon is a symbol of power and agility. This species was once critically endangered, but it is making a comeback in Ontario.

Classification and Phylogeny

The common ancestor of all animals was likely a colonial, flagellated protist that lived at least 700 million years ago. Biologists have hypothesized that a spherical arrangement of cells in a colony might have become indented, forming a hollow cavity. This cavity would have helped the organism capture and digest food (**Figure 3**). This same basic arrangement and indenting process can be still observed in the embryonic development of animals today. Some cells in the colony may also have become specialized for feeding. This double-layered arrangement of cells with a lining of specialized digestive cells is very similar to that of sponges, the simplest of all modern animals. (See Figure 7, page 99.)

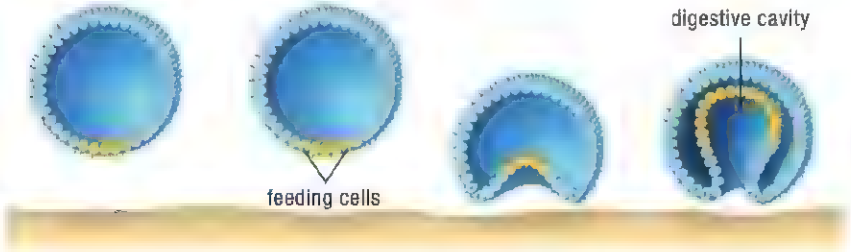


Figure 3 Scientists believe that animals evolved from colonial protists. The protists developed a hollow body cavity and specialized feeding cells. Over time, the colonies evolved into multicellular organisms with specialized tissues.

A key early innovation among animals was the development of nerves—specialized cells used to coordinate movements and sense changes in the environment. Animals in the Porifera phylum, such as modern sponges, are the only ones that do not have this key animal feature.

Another major division among animal phyla is between those with radial symmetry and those with bilateral symmetry. The bodies of animals with **radial symmetry** are regularly arranged around a central axis, like the spokes of a wheel. Jellyfish, for example, have radial symmetry. The bodies of animals with **bilateral symmetry**, such as humans, have left and right sides that are mirror images of each other. As you can see in **Figure 4**, bilaterally symmetrical animals also have different dorsal (upper) and ventral (lower) surfaces as well as an anterior (front) and posterior (back) end.

radial symmetry symmetry around a central axis

bilateral symmetry symmetry around a midline

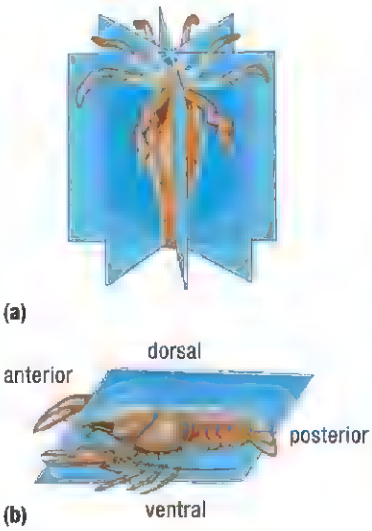


Figure 4 (a) Radial symmetry and (b) bilateral symmetry

protostome an animal with bilateral symmetry; during embryonic development, the mouth forms before the anus

deuterostome an animal with bilateral symmetry; during embryonic development, the anus forms before the mouth

vertebrate an animal with a backbone or a notochord

notochord a flexible rod found in some chordates; in most modern chordates it is replaced by vertebrae during embryonic development

invertebrate an animal that does not have a backbone; the great majority of animal species are invertebrates

Bilaterally symmetrical animals are further divided into two major branches. The **protostomes** and **deuterostomes** are distinguished by different patterns of embryonic development. Humans belong to the deuterostome phylum Chordata. The Chordata are almost entirely **vertebrates**—animals with a dorsal backbone or **notochord**, including fish, amphibians, reptiles, birds, and mammals. All other animals are referred to as **invertebrates.**

Figure 5 is a phylogenetic tree based on recent evidence from genetics and molec ular biology. It illustrates one current hypothesis about the evolutionary relationships of 10 major phyla of animals. There are seven more animal phyla that are not shown on this tree, but they include relatively few species.

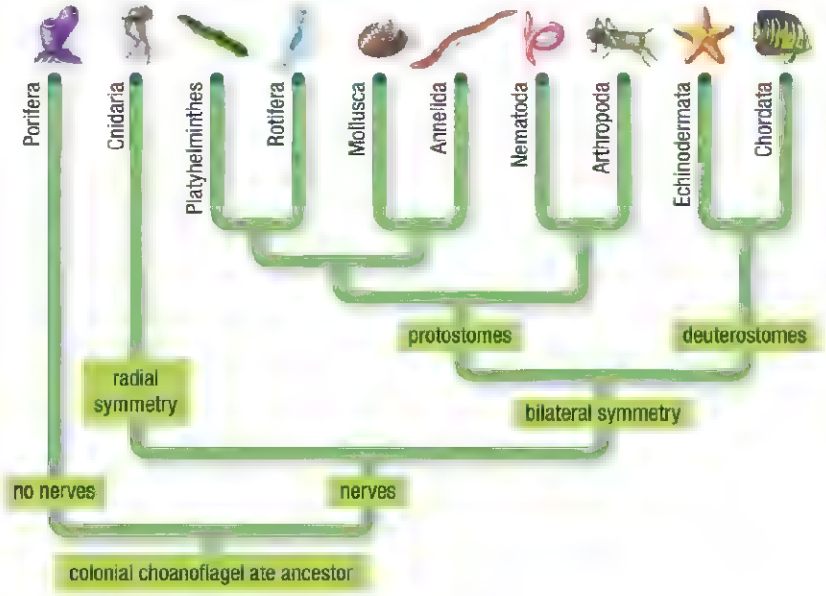


Figure 5 This phylogenetic tree of the Animal Kingdom is based on recent evidence from genetics and molecular biology. The tree shows 10 of the 17 animal phyla.

Characteristics

All animals are multicellular heterotrophs that use oxygen for aerobic respiration. Unlike plants and fungi, animal cells do not have cell walls. Their cell membranes are in direct contact with each other. Animals feed on plants, fungi, protists, and each other. A number of animals also have symbiotic relationships with autotrophs that provide a supplementary source of food.

germ layer one of three layers that form during early embryonic development in most animals

coelom a body cavity present in some animals; contains the animal's internal organs

Cell Specialization and Germ Layers

The nerve cells developed by the first animals are just one of the many specialized cell types in animals. These cells become specialized during embryonic development.

One way that animal phyla are distinguished from each other is by the number of germ layers their members have. **Germ layers** are the layers of cells in a developing embryo that give rise to specialized tissues. There are three germ layers: the ectoderm (*ecto* meaning "outer" and *derm* meaning "layer"), the endoderm (*endo* meaning "inner"), and the mesoderm (*meso* meaning "middle"). The ectoderm gives rise to the skin and nervous system. In some complex animals ectoderm cells produce shells, scales, feathers, hair, and nails. The endoderm forms the inner lining of the gut and, in some organisms, the respiratory system. The mesoderm gives rise to the circulatory, reproductive, excretory, and muscular systems.

Another feature that distinguishes animal phyla is whether or not the animals have a body cavity, or **coelom**, containing the internal organs (**Figure 6**). The coelom develops from the animal's mesoderm.

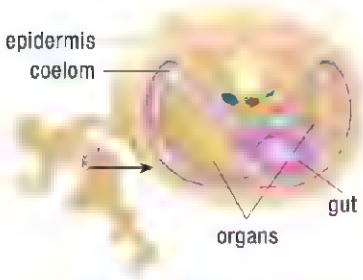


Figure 6 Most animals have one of two types of coelom.

The Simplest Invertebrates

The phyla Porifera and Cnidaria include the simplest invertebrate animals. The Porifera include about 8000 species of sponges. As illustrated in **Figure 7**, sponges have a simple body plan with flagellated cells, called choanocytes, lining a central cavity. The flagella create a continuous current of water that passes through pores in the body wall and exit through large openings at the top of the sponge. Food particles entering with water are captured by the choanocytes. Porifera are sessile as adults and range in size from 1 cm to 2 m across (**Figure 8(a)**). Most sponges are hermaphrodites that release sperm into the surrounding water. Their eggs remain within their bodies and are fertilized by other sperm that are drawn in with water. The fertilized eggs develop into ciliated larvae that swim or crawl in search of a suitable location to settle and grow.

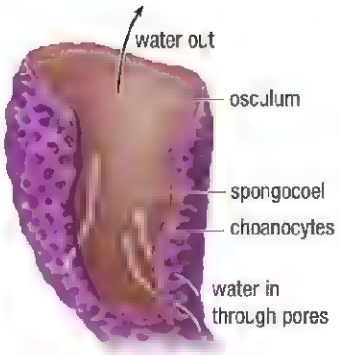


Figure 7 Sponges have a simple body plan with two main layers. The inner layer consists of specialized feeding cells called choanocytes that are similar in structure to some protists.

Most sponges are marine, but there are more than 100 freshwater species, including some that are common in Ontario. Freshwater sponges are often mistaken for plants because they contain symbiotic blue–green algae, or cyanobacteria. Marine sponges can be very abundant, and they play important ecological roles as food and shelter for many other organisms—for example, large sponges can harbour thousands of shrimp. Sponges are also commercially valuable and are threatened by overharvesting in some regions.

The Cnidaria include close to 9000 species of hydras, anemones, jellyfish, and coral animals (**Figure 8(b)** and **(c)**). They do not have a mesoderm and exhibit radial symmetry. They are the simplest animals with specialized nerve, muscle, digestive, and reproductive tissues. All cnidarians have tentacles with stinging cells that contain **nematocysts**, which are capsules containing a barbed, thread-like tube that delivers a paralyzing sting when propelled into attackers and prey.

nematocyst a capsule within specialized cells of cnidarians containing toxins that can be propelled toward attackers and prey, causing them to become paralyzed; also called a stinging cell

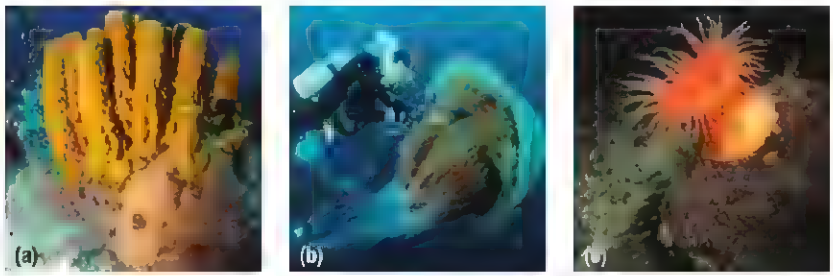


Figure 8 (a) Porifera like this tube sponge are considered the simplest animals. (b) Some cnidarians, like this giant Nomura jellyfish, can measure 2 m across and exceed 200 kg in weight. Some are free swimming, while others, like (c) this anemone, are sessile.

Coral animals are cnidarians that produce external skeletons made of calcium carbonate. Over time, these skeletons can accumulate, and large communities of coral animals can create gigantic coral reefs. These reefs form complex structures and provide habitat for thousands of other marine species. They are considered the most biologically diverse of all aquatic ecosystems (**Figure 9**).

Although the status of many cnidarians is not known, 236 species are considered at risk, mostly due to pollution and habitat destruction. The effects of greenhouse gases and climate change on water chemistry and temperatures may prove to be an even greater problem. Today, most of the world's coral reefs are seriously threatened.

A local species of cnidarian is the freshwater jellyfish *Craspedacusta sowerbyi*. This jellyfish is harmless to humans, but it is an invasive species that is spreading around the world. It was first reported in Ontario in 1980.

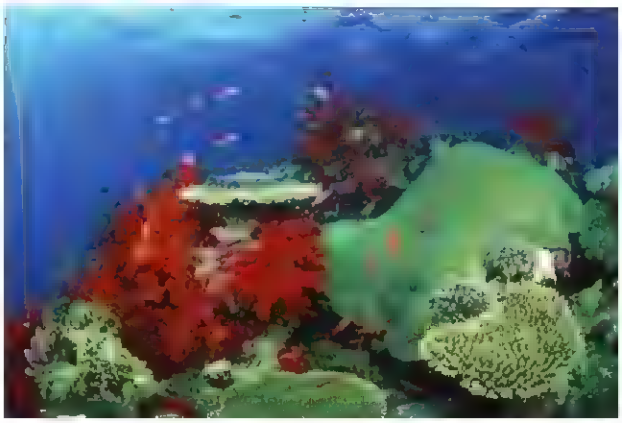
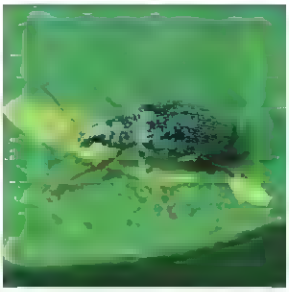
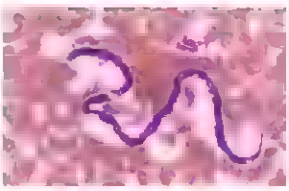


Figure 9 Communities of coral animals can build complex reefs that are home to many other species.

The Protostome Invertebrates

The protostome invertebrates include six major animal phyla and the vast majority of all animal species (**Table 1**). They occupy almost every environment and in many cases are extremely abundant.

Table 1 The S x Major Phyla of Protostome Animals

Phylum (common name)	Examples (Animals shown in the photos are bolded.)		Key features
Arthropoda (arthropods)	**insects**, spiders, mites, ticks, millipedes, centipedes, scorpions, daphnia, crabs, lobsters, shrimps, barnacles		• They have segmented bodies with jointed appendages. • They have complex sensory systems including antennae. • Their hard outer skeletons contain chitin. • They have highly variable body shapes. • They have complete digestive, excretory, and circulatory systems. • Their respiratory systems use gi ls or internal a.rways. • They range in size from 0.1 mm to 1 m in length. • They are extremely diverse and play vital roles in all aquatic and terrestrial ecosystems, often as the primary consumers. • Insects are the only invertebrates capable of flight. • About 1 100 000 species have been described (> 75 classes)
Nematoda (roundworms)	pinworms, **dog heartworms**		• They have unsegmented cylindrical bodies with complete digestive tracts • Many are important parasites of other animals. • Some females can produce more than 100 000 eggs each day. • They live in very large numbers in the soil and aquatic sediments. • They range in size from 2 mm to 2 m in length. • About 20 000 species have been described (2 classes)
Annelida (segmented worms)	earthworm, **feather-duster worms**		• Their bodies and most of their internal organs are segmented. • They have complete digestive systems. • Gas is exchanged through the skin, gills, or other specialized body parts. • Most have bristles on their outer surface to help with movement. • Many are marine. • They range in size from 0.5 mm to 3 m in length. • About 14 000 species have been described (7 classes).
Mollusca (mollusks)	**snails**, clams, octopuses, squid		• They have three main unsegmented body parts: a foot, a visceral mass, and a mantle that secretes a shell. • Almost all have specialized file-like radula used for scraping and boring • In some species the shell is reduced or absent. • They have complete digestive systems, circulatory systems, and gills. • They range in size from less than 1 cm to 20 m in length. • About 120 000 species have been described (8 classes).
Rotifera (rotifers)	**rotifers**		• They are small aquatic animals (less than 2 mm long). • They use cilia to direct food into their mouths. • Most live in fresh water. • They have no respiratory or circulatory system. • They are very important consumers in many aquatic food webs. • About 1800 species have been described (3 classes).
Platy-helminthes (flatworms)	**tapeworms**, liver flukes		• They are flattened, unsegmented worms. • Most have a digest ve cavity with a single opening. • They do not have coeloms. • They range in size from 1 mm to 5 m in length. • Many are important parasites of other animals. • They have no circulatory or respiratory system. • About 14 000 species have been described (4 classes).

Body Plans and Life Cycles

The body plans and life cycles of protostomes are extraordinarily diverse. **Figure 10** shows a representative body plan from the most biologically successful class of organisms—Phylum Arthropoda, Class Insecta.

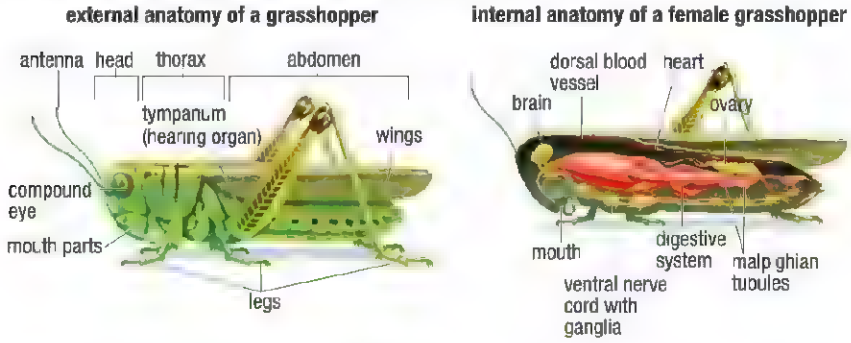


Figure 10 There are more known species of insects than of any other class of organisms on Earth. Their success is due in large part to an efficient body plan that includes nervous, digestive, respiratory, excretory systems and reproductive systems; advanced sensory structures; and the ability to fly.

Other characteristic body features of protostomes include the powerful claws of crabs and lobsters, the tentacles of octopuses and squid, the ornate shells of snails and clams, and the large, colourful wings of butterflies.

Many animals, including insects, have a life cycle that involves a number of distinct larval stages. In these life cycles, the larval stages are sometimes unrecognizable when compared to the adult. **Figure 11** shows examples of four larvae.

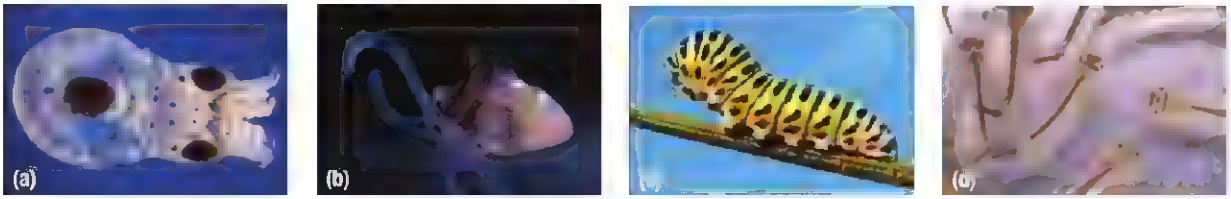


Figure 11 The larval stages of an (a) octopus, (b) snail, (c) butterfly, and (d) mosquito.

Research This

Invertebrate Diversity

Skills: Researching, Evaluating, Communicating

SKILLS HANDBOOK A2.1, A5.1

The invertebrate animals are both abundant and diverse. You may be familiar with insects and spiders, but you are probably much less familiar with some other invertebrate groups. In this activity, you will have an opportunity to survey these diverse groups and share your findings with your classmates.

1. Choose one of the ten invertebrate phyla shown in Figure 5 on page 98.
2. Use the Internet and other resources to gather information on the following topics:
   (i) the distinguishing features of the phylum
   (ii) the general appearance and body plan
   (iii) a typical life cycle
   (iv) the ecological roles of members of the phylum
   (v) features or characteristics of particular significance or concern

A. Prepare a poster or other presentation about your chosen group that you can share with the class. Your goal is to showcase the contribution of your chosen phylum to the overall diversity of life. T/I C

GO TO NELSON SCIENCE

Human–Protostome Interactions

The protostomes include many species that are of great consequence to humans and interact with us in direct ways. They affect our food supply, our health, and our economy.

COMPETITORS

Figure 12 Tomato hornworms are common pests in Ontario. These caterpillars feed on tomato plants, including the fruit.

Many protostomes compete with humans for food. Insects are some of the best known competitors. Virtually every food crop has a number of important insect pests. For example, important pests of Ontario corn crops include at least 13 different species of insect and one species of slug (Phylum Mollusca) (**Figure 12**).

Food losses due to such competitors are significant, and the cost of controlling these pests can be a major factor in the cost of food production. Most crops are planted in large monocultures. This, along with the ability of many insects to reproduce quickly, allows insect populations to grow very quickly. Pesticides can keep pest populations in check, but some insects are becoming resistant to pesticides. Pesticides can also damage the environment and pose risks to human health. Organic and alternative farming methods can eliminate or reduce the use of synthetic pesticides. They rely instead on the presence of natural or introduced predatory insects to control pests.

Insects are also serious pests of other commercially valuable plants including trees and cotton. The spruce budworm, gypsy moth, Asian long-horned beetle, and mountain pine beetle are examples of insects that have caused significant damage to forests.

PATHOGENS AND VECTORS

Humans suffer from many parasitic diseases. Some are caused by protists, but others are caused by animals—particularly species of nematodes, tapeworms, and flukes. Various nematode parasites are capable of infecting many body tissues. Adult tapeworms inhabit intestines and pass their fertilized eggs out with feces (**Figure 13**). Parasitic flukes often live in lungs or blood vessels. One blood fluke that normally infects waterfowl is responsible for "swimmer's itch."

In addition to causing disease, many biting animals are vectors—they spread disease. For example, mosquitoes spread malaria, yellow fever, and West Nile virus from person to person. Ticks and fleas spread Lyme disease and the plague. Controlling the spread of these diseases involves controlling the animal vectors.

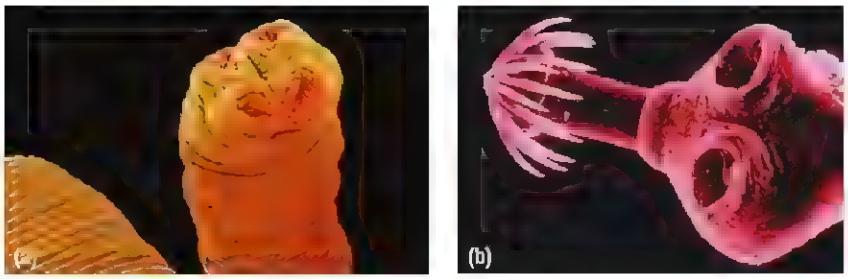


Figure 13 (a) A tapeworm has a specialized head, or scolex. (b) Some tapeworms have heads with barbs and suckers for attaching to the wall of the intestine.

FOOD AND ECONOMIC BENEFITS

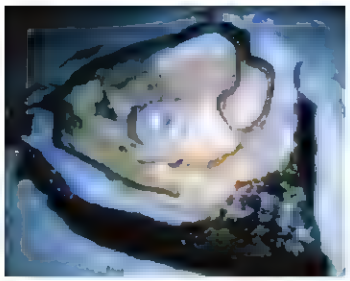


Figure 14 Some oysters secrete a protective hard coating around a foreign particle, such as a grain of sand, forming a pearl.

Many protostomes benefit humans. We eat many of these animals, including mollusks such as clams and scallops, crustaceans such as shrimp and lobsters, and the honey produced by bees. We use oysters for food and as a source of pearls (**Figure 14**). Coral reefs are used in some countries as a source of minerals for cement production, and silk is a very valuable fibre produced by caterpillars of the silkworm moth. Perhaps the greatest direct value we receive from protostomes is the pollination of food crops by insects. If plants are not pollinated, they do not produce seeds, and many do not produce fruit.

The Deuterostomes

The deuterostomes are a much less diverse but much more familiar collection of animals. This branch of the animal phylogenetic tree includes two main groups: the echinoderms (starfish, sea urchins, sea cucumbers, and their closest relatives) and the chordates (vertebrates and their closest relatives).

The Echinoderms

The 6500 species of echinoderms are the only invertebrates that exhibit the same pattern of early embryonic development as the vertebrates. The immature stages of echinoderms are free swimming and bilaterally symmetrical. As they grow, they develop a radially symmetrical pattern around five or more arms (**Figure 15(a)**).

Adult echinoderms have a unique body plan. They have a complete digestive system, a simple circulatory system, and no respiratory or excretory system. They do not have a head region, and their nervous system circles the mouth and extends into the arms. Echinoderms move using a water-filled vascular system that uses the principles of hydraulics. By pumping water with muscle action and opening and closing valves within the system, echinoderms can control the movements of their arms and tube feet (**Figure 15(b)**). This system also allows them to easily generate considerable force. Some starfish use this ability to pull apart large clams and feed on them.

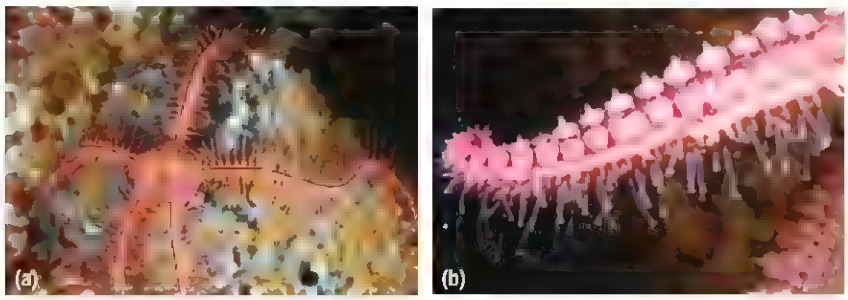


Figure 15 (a) Echinoderms such as this brittle star are bilaterally symmetrical as larvae but radially symmetrical as adults. (b) Echinoderms move using a system of water-filled canals that control their arms and tube feet.

The Chordates

The chordates include fish, amphibians, mammals, reptiles, and birds. Although the birds are discussed here as a separate class, they are now considered a recently evolved group of reptiles.

The chordates include the most complex living organisms. They are thought to have evolved from bilaterally symmetrical ancestors with segmented bodies. These primitive chordates had gill slits, a dorsal nerve cord, and a flexible rod called a notochord. The notochord acted as an anchor for attaching the body wall muscles (**Figure 16**). These features probably enhanced the chordate's ability to move. In primitive chordates and many modern chordates the gill slits are used for filter feeding.

Over time a number of other important features evolved, including vertebrae, paired appendages, a bony skeleton, and more highly developed brain and sensory systems. Internal supporting skeletons enabled chordates to develop large body sizes—most vertebrates are many times larger than the vast majority of invertebrates. The blue whale, a vertebrate, is believed to be the largest animal that ever lived.

A key development that enabled some of the vertebrates to conquer land was the evolution of a waterproof amniotic egg. An **amniotic egg** has specialized membranes and an outer shell that make it resistant to water loss. Mammals, including humans, retain amniotic membranes around the developing fetus. Only a few species of mammals, including the platypus and the echidna, still lay shelled eggs.

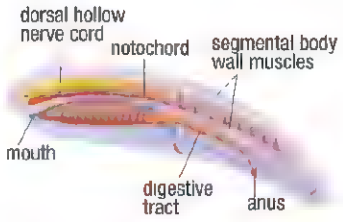


Figure 16 These are the distinguishing features of the common ancestor of all chordates. The simplest living chordates still retain this body form.

amniotic egg an egg with an outer leathery or hard shell and specialized internal membranes that protect and nourish the embryo

The phylogenetic tree in **Figure 17** indicates major features that arose in the evolutionary history of the chordates. The birds are shown as a distinct group, although they are now considered to belong to the reptile clade.

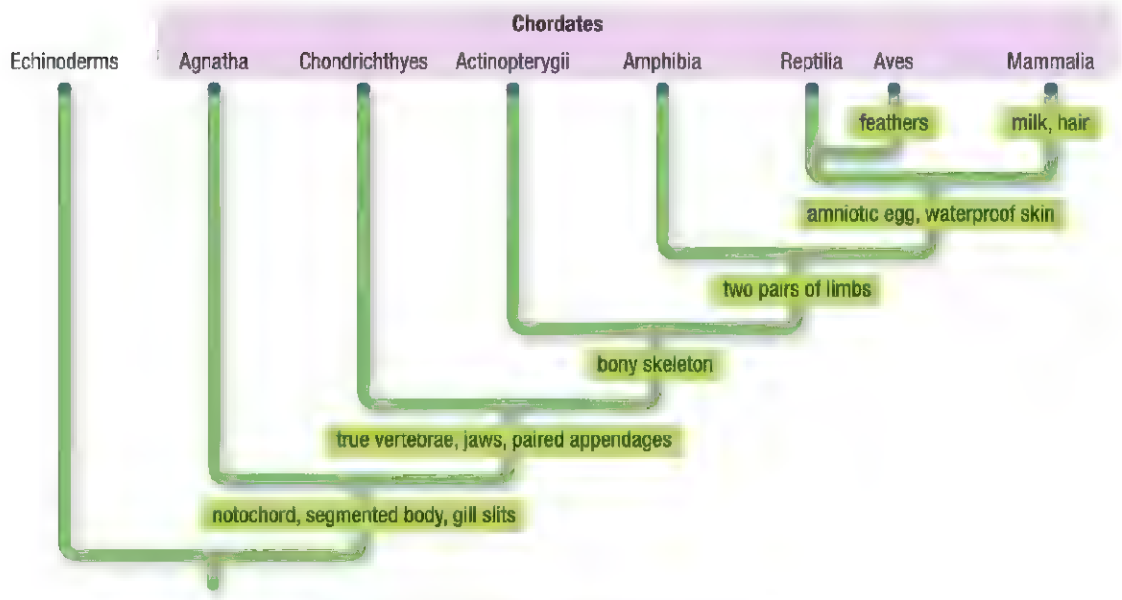


Figure 17 The phylogenetic tree for the deuterostomes

THE VERTEBRATE SUCCESS STORY

Most chordates are vertebrates—their dorsal nerve cord is enclosed within a spinal column and cranium, or skull. The spinal column is divided into separate segments called vertebrae. Except for the earliest fish, all vertebrates have a well-defined head containing a cranium that surrounds and protects an enlarged brain. Unlike the external skeleton of arthropods, which the animal must shed in order to grow, the internal skeleton of vertebrates can grow along with the animal's body. The enlarged and protected brains and eyes, ears, and noses characteristic of vertebrates provide advanced sensory capability and enable coordinated behaviours and motion.

The majority of vertebrate species are fish. Their vertebrate skeletons and large brains enabled them to become powerful and agile swimmers, far surpassing the swimming capabilities of any invertebrates. Over time some fish evolved paired appendages, which gave rise to bony limbs. These fish were to be the ancestors of early amphibians and all land vertebrates.

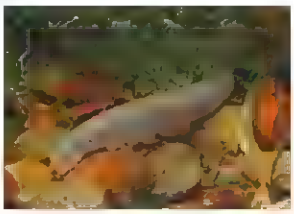
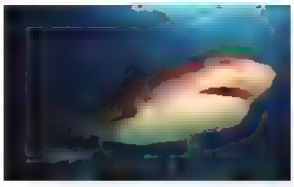
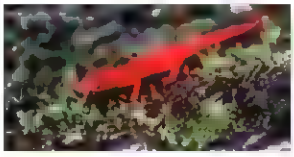
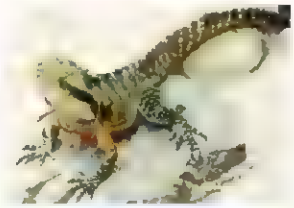
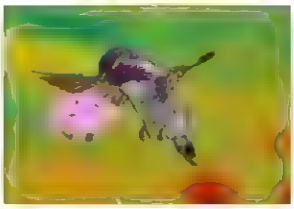
Figure 18 This leatherback sea turtle hatchling will scurry across the sand to reach the ocean, where it will spend most of its life

Vertebrates evolved a number of key features that enabled them to conquer the land. Beginning with the limbs that allowed early amphibians to support their bodies on land, early reptiles evolved protective outer skin, enhanced lungs and circulatory systems, internal fertilization, and eggs with outer shells (**Figure 18**).

Although greatly outnumbered by invertebrates, vertebrates are nonetheless a diverse and dominant group of animals. Vertebrates have the most advanced organ systems and the most complex behaviours of all organisms. These features, along with their large size, enable them to inhabit many aquatic and terrestrial environments. In addition, birds and mammals can maintain warm body temperatures. This lets them remain active in very cold environments when all other forms of life are dormant.

Table 2 highlights the major taxonomic groups within the vertebrates. Notice that the first three groups are often collectively referred to as "fish," but they are actually quite distinct groups.

Table 2 The Vertebrates

Class	Examples (Animals shown in the photos are bolded.)		Key features
Agnathans (jawless fishes)	**lamprey**, hagfish		• Their skeletons are made of cartilage they have no jaws, and a notochord is present in adults. • They have gill slits but no paired appendages. • Hagf sh are scavengers. • Many lampreys are parasites of fish. • Lampreys have larval forms that are filter feeders. • There are marine and freshwater species. • About 60 species have been descr bed.
Chondrich-thyes (cartilaginous fishes)	**sharks**, rays, skates		• Their skeletons are made of cartilage • They have jaws, vertebrae, gill slits, and paired appendages. • Their fins are often thick. • Many are predators of other fish. • Reproduction uses internal fertilization. • Most species are marine. • About 850 species have been described.
Actinopterygii (bony fishes)	most common fish—bass, **trout**, tuna, salmon		• Their skeletons are bony. • Most have a swim bladder—a gas-filled organ used to control buoyancy. • Their fins are often membrane-like with stiff "rays" for support. • Most species use external fertilization. • There are marine and freshwater species. • About 24 000 species have been described.
Amph bia (amphibians)	frogs, **salamanders**, caecilians		• Most have an aquatic larval stage with gills. • Adults are tetrapods—having four limbs adapted for moving on land (except caecilians). • Most species use external fertilization. • They breathe through their lungs and/or skin • About 5000 species have been described.
Reptilia (reptiles and birds*) *Birds are described separately.	snakes, **lizards**, crocodilians		• Most are terrestr al tetrapods with dry scaly skin. • They breathe with lungs. • They use internal fertilization. • They have amniotic eggs with soft shells. • Turtles lack teeth and have a bony shell. Aquatic species have webbed feet • Turtles are the most distantly related group within the reptile clade. • About 7300 species have been described.
Aves (birds)	birds		• They are tetrapods with forelimbs modified as w ngs. • Most species are capable of flight. • They have feathers. • They are warm blooded (endothermic). • They have large brains and acute vision. • They use internal fertil zation. • They lay hard-shelled amniotic eggs. • About 9700 species have been described.
Mammalia (mammals)	mammals		• They are tetrapods and have hair. • They nurse their young with milk produced in mammary glands. • They are warm-blooded (endothermic). • They have large brains and acute vision and sense of smell. • They use internal fertil zation. • Most give birth to live young; a few species produce amniotic eggs • About 4500 species have been described.

Investigation 3.3.1

Representing the Six Kingdoms of Life (page 111)

You can now complete Investigation 3.3.1.

In this observational study you will examine a representative species from each kingdom and complete a concept map that highlights its key features.

VERTEBRATE DIVERSITY AND THE WEB OF LIFE

Although greatly outnumbered by invertebrates, vertebrates are a diverse and important group of animals. When you hear the word "fish," "snake," "frog," "bird," or "mammal" you may envision "typical" examples. You might even think that the members of each of these groups are quite similar. How different is one kind of fish from another kind of fish, or one kind of snake from another? Is there really that much difference between frog or bird species? Do all mammals not have very similar characteristics?

As you have learned throughout this unit, species are grouped according to many shared features, but each species possesses a unique set of features that sets it apart from every other species on Earth. The examples listed in **Table 3** are just a tiny sampling of the countless unusual and extraordinarily diverse vertebrates.

Table 3 Highlighting Vertebrate Diversity

Feature	Examples
Size	• Blue whales can have a mass of more than 150 000 kg. Their hearts alone can have a mass of 600 kg. They give birth to a single calf with a mass of more than 2500 kg. The calf drinks 400 L of milk each day! • The smallest bird is the bee hummingbird of Cuba. It has a mass of just 1.8 g, the same as a dime. This extraordinarily small flying machine is capable of beating its wings 80 times per second and visiting more than 1000 flowers in a single day.
Sensory ability	• Echolocating bats can detect an echo off an object as small as a mosquito. They can also produce and detect sounds with frequencies far beyond the range of human hearing. • Pit viper snakes have the ability to detect infrared radiation. Special pits on the sides of their heads detect this thermal energy, which is given off by warm-blooded mammals and birds.
Behaviour	• The longest migration of any animal is that of the arctic tern. Their annual zigzagging return trip can cover a distance of over 71 000 km! • Arctic ground squirrels, in contrast, hibernate over the winter. Arctic winters are so long that these ground squirrels spend more than 80 % of their lives asleep
Life cycles	• Finding a mate in the deep ocean is extremely difficult. So when the tiny male angler fish finds one, he bites onto the body of the female and remains attached to her for the rest of his life. The body of the female grows into the mouth of the male, and their circulatory systems fuse. When the female is releasing her eggs, hormones in her blood travel into the body of the male and cause it to release sperm • Females of the recently extinct gastric brooding frog swallowed their fertilized eggs. The eggs hatched in their mother's stomach, and the tadpoles developed there fully before climbing up her throat and hopping away!

Figure 19 Roots and Shoots and the Jane Goodall Foundation promote environmental awareness and the protection of gorillas. Jane Goodall began her monumental work with wild gorillas in 1960.

WEB LINK

To learn about environmental organizations and how you can get involved,

GO TO NELSON SCIENCE

Humans have a special interest in mammals and birds. This is partly because of their fascinating diversity of forms and behaviours, but it is no doubt also because we are vertebrates. This may explain why humans are much more likely to be concerned about threats to these species than they are about threats to invertebrate species or species in other kingdoms. Many people join organizations to help protect endangered mammals and birds, but few organizations focus on saving invertebrates, fungi, or plants.

Fortunately, most current efforts to protect the environment and the diversity of life on Earth focus on protecting habitats and entire ecosystems. Concern over species such as panda bears, polar bears, and gorillas captures public interest and media attention (**Figure 19**). If this interest is used to protect the ecosystems to which these wonderful species belong, the entire web of life within those ecosystems benefits. In this way, our interest in the vertebrates may be our most powerful means of protecting the diversity of life.

3.3 Summary

- Animals are an extremely large and diverse group of heterotrophic multicellular eukaryotes.
- Almost all animals are motile and have nerves that coordinate body movements and process sensory information.
- Animals are very diverse in their morphology and life cycles.
- Most animals develop from an embryo with three germ layers: the endoderm, the mesoderm, and the ectoderm.
- The simplest animals are the Porifera and the Cnidaria.
- Most animals are protostomes: arthropods, nematodes, mollusks, annelids, rotifers, or platyhelminthes.
- Humans have many important interactions with protostomes.
- The chordates are the most complex of all organisms and include the vertebrates: fish, amphibians, mammals, reptiles, and birds.
- The evolution of a bony skeleton, paired limbs, waterproof skin, and an amniotic egg enabled vertebrates to survive on land.
- The diversity of animals is threatened by many human activities, including habitat destruction, pollution, and climate change, but our affinity for animals motivates us to protect them and their habitats.

3.3 Questions

1. Animals, plants, and fungi are all multicellular eukaryotes. What unifying characteristics distinguish animals from members of these other two kingdoms? K/U
2. List several ways in which humans depend on other animal species. K/U
3. Make sketches to illustrate the way scientists believe the earliest animals evolved from colonial protists. K/U C
4. Copy the table below into your notebook. Then place the following terms in the correct columns. K/U C

   bilateral symmetry, asymmetrical, nerves present, nerves absent, protostomes, deuterostomes

annelids	chordates	rotifers	arthropods	porifera	nematodes

5. Which body system does each of the three germ layers give rise to? K/U
6. Which key marine ecosystems are the Cnidaria most closely associated with? What threatens the ecosystems? K/U
7. State two key characteristics and two examples for each of the following phyla: K/U C
   (a) Mollusca (b) Nematoda
   (c) Arthropoda (d) Annelida
8. The platyhelminthes are considered simple but important animals. Justify this description. K/U C
9. Humans compete with many insects for valuable resources. Give examples to support this statement. C A
10. Many animals cause serious diseases, either as parasites or vectors. Research how each of the following animals is involved in a human disease: T/I
    (a) anopheles mosquitoes
    (b) tsetse flies
    (c) *Schistosoma* flukes
11. What five major evolutionary advances are shared by all mammals, reptiles, and birds? Explain the benefit of each advance. K/U C
12. What special feature of birds and mammals has enhanced their ability to survive in cold climates? K/U
13. Marine ecosystems are vulnerable to human actions but often remain hidden from our view. The coral reefs in the Caribbean are subject to many human impacts and are in a general state of decline. Use the Internet and other sources to learn about the status of the Caribbean reefs. T/I
    (a) What are the major human factors that have caused their decline?
    (b) What is a lionfish? How is it influencing these reefs?
    (c) How is climate change expected to affect these reefs?
14. Gastric brooding frogs were last seen in 1985. The two known species are now thought to be extinct. Recently a few amphibians that were thought to be extinct have been rediscovered. Use the Internet and other sources to investigate the search for these and other missing species. T/I

GO TO NELSON SCIENCE

3.4 Explore an Issue in Biodiversity

SKILLS MENU

- Researching
- Identifying Alternatives
- Analyzing
- Defending a Decision
- Communicating

Fisheries in Peril

The world's marine ecosystems supply humans with a rich supply of high-quality foods. These foods include a great diversity of animals ranging from oysters, squid, and sea cucumbers to lobsters, shrimp, and fish. Many of these animals are harvested from natural populations, and others are "farmed" in cages or other engineered structures.

Tragically, many scientists believe that more than half of all major fisheries are unsustainable and in decline. Many different kinds of fisheries are at risk, including wild tuna and salmon, wild shrimp, north Atlantic cod, and many of the world's large shark species. Scientists also believe that some fisheries are causing serious environmental damage to natural ecosystems (**Figure 1**).

LEARNING TIP

A Fishery

The commercial harvesting of fish or any other aquatic organism is generally referred to as a fishery.

Figure 1 Overharvesting, among other factors, may put this jack mackerel fishery at risk of collapsing.

UNIT TASK BOOKMARK

Consider the status of your chosen group of organisms. Are they threatened or endangered? How sustainable are the ecosystems they belong to?

The Issue

How can fisheries become more sustainable? The federal government of Canada wants to evaluate the sustainability of a particular fishery, using the best data available. It also wants recommendations for ways the fishery can become more sustainable.

You are part of an advisory group that has been commissioned to explore this issue. The group includes

- a Government of Canada fisheries scientist
- a commercial fisher
- a consumer
- an environmentalist
- a representative of a First Nation community that depends on small-scale fishing

Your group will present your findings and recommendations to a government panel that includes the federal ministers for the departments of Fisheries and Oceans Canada and Foreign Affairs and International Trade Canada.

Goal

Your group's goal is to present a summary of the current status of your chosen fishery and outline a management plan to ensure that the fishery becomes sustainable. The plan will guide the Government of Canada's fisheries policy.

Research

Choose one of the roles listed above or another stakeholder of your choice. What position do you approach the issue from? What factors will you want to consider in your recommendations to the government panel? With your fellow group members, conduct research to inform your position. Use the following questions to help guide your research:

- Is the fishery based on a natural population or a farmed species?
- Where is the species being harvested, and by what method?
- Where is the major market for this species? Does Canada import and/or export this species?
- What economic and/or political pressures are influencing the fishery? How are they affecting it?
- What environmental pressures are influencing the fishery (for example, pollution, climate change)? How are they affecting it?
- Is this species considered an essential food or a luxury food?
- Is the current rate of harvest sustainable? Is the demand likely to increase or decrease in the future?
- Are there other environmental concerns related to this fishery?
- How could harvesting and/or farming methods be improved? Are any new technologies being developed?

Identify Solutions

Based on your research, identify ways that the fishery can become more sustainable or improve its current practices.

- How can harvesting and/or farming methods be improved for this fishery?
- Is the demand for this species justified? If not, what actions could help reduce the demand?
- What role can consumers play in making this fishery more sustainable?

CAREER LINK

Fisheries Officer

Fisheries officers help protect fisheries and habitats and enforce Canada's Fisheries Act. To learn more about a career as a fisheries officer,

GO TO NELSON SCIENCE

Make a Decision

Based on the information you have gathered, determine how sustainable the fishery is and compile a set of recommendations for improvements to the fishery.

Communicate

As a group, choose a suitable and creative format for presenting your information to the government panel.

Plan for Action

Canadians are major consumers of fisheries products. Many of these products being sold in Canada are not produced in a sustainable way. Investigate the availability of fisheries products in your own region, and consider ways to enhance and encourage sustainable fisheries.

1. Visit one or more grocery stores that sell fisheries products and identify 10 to 15 fisheries products available. Note the country of origin for each product and, if possible, whether it was harvested from a natural population or farmed.
2. Share your findings in a small group. Discuss the sustainability of these particular fisheries products. Then brainstorm ways in which you could take action to enhance the sustainability of one or more of these fisheries.
3. Use the Internet and other sources to find out which organizations are involved in raising public awareness about fisheries issues. Consider their recommendations for citizen action.
4. Prepare a brief Plan for Action that outlines the specific activities you could complete in an effort to enhance or encourage sustainable fisheries.
5. Present your Plan for Action to the class and consider putting your plan into action!

GO TO NELSON SCIENCE

CHAPTER 3 Investigations

Investigation 3.1.1 CONTROLLED EXPERIMENT

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Growing and Observing Fungi

Fungi often cause food to spoil. Fungi can attack food in the field, during transportation and processing, and after it reaches you. In your home, foods may be protected in a number of ways. In this investigation you will design controlled experiments to test two factors that may influence the growth of bread mould.

Testable Question

Choose two of the following independent variables for your experiment: temperature, light, and chemical preservatives. Write a testable question for each variable. For example: Does temperature influence the growth of bread mould?

Predictions

Predict the answer to each of your testable questions.

Variables

Identify the independent (manipulated) variable and dependent (responding) variable in each experiment. List other variables that will be controlled

Experimental Design

Design experiments to manipulate your chosen independent variables and monitor their effects on the growth rates of mould. Consider using conditions similar to those in your home. Have your teacher approve your experimental design before you begin your experiments.

Equipment and Materials

- eye protection
- apron
- Petri dishes
- tape
- refrigerator and incubator
- hand lens or dissecting microscope
- white bread, with preservatives
- white bread, without preservatives

Procedure

1. Conduct your experiments.

Caution: Once you have placed your bread samples in the Petri dishes, seal them with tape and do not open them again. Your teacher will outline proper procedures for disposing of your samples at the end of the experiment. If you are allergic to mould, inform your teacher immediately.

2. Put on your eye protection and lab apron. Without opening the Petri dishes, use a hand lens or dissecting microscope to observe your samples of bread.
3. Choose a sample that has developed coloured spores. Make a labelled biological drawing of the mould. Consult print and online resources to help you identify the structures you observe. If possible, identify the species of mould.

Analyze and Evaluate

(a) What variables were measured, recorded, and/or controlled in this investigation? Which variables were manipulated and which were responding? What type of relationship was being tested? K/U T/I A

(b) Prepare and submit complete laboratory reports of your controlled experiments. C T/I A

Apply and Extend

(c) Based on the results of your experiments, what conditions would you recommend for minimizing mould growth? T/I A

(d) Why might people prefer to eat bread without chemical preservatives, even if the preservatives protect the bread from mould growth? T/I A

(e) Research how to make a mushroom "spore print." How and why are they used? Consider making your own spore prints. T/I A

GO TO NELSON SCIENCE

Investigation 3.3.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Representing the Six Kingdoms of Life

Each kingdom of life includes a great diversity of species with their own sets of unique physical characteristics and behaviours. These species also share distinguishing features with other species in their kingdom. In this investigation you will examine a representative species from each of the six kingdoms and complete a concept map that highlights these features. You will also make a biological drawing of each representative species.

Purpose

To complete a concept map for each of the six kingdoms of life by observing representative species; to make biological drawings of the representative species

Equipment and Materials

- gloves
- six specimens (or images), one from each kingdom of life, placed at separate stations
- hand lens
- microscope
- biology reference books
- blank Kingdom Concept Maps

Procedure

1. Review the information needed to complete each concept map. Keep this information in mind as you examine each specimen.
2. You will have limited time at each station, so use your time wisely. Carefully observe each specimen and make a detailed biological drawing of the organism.
3. After observing and drawing each specimen, begin completing the concept maps. Use the features you observed to identify the kingdom each organism is from.
4. You may use print and online resources to learn more about your specimen and help you complete the concept map.

Analyze and Evaluate

(a) Which features did you find most useful for identifying the kingdom each of the eukaryotic organisms belonged to? T/I

(b) Do you think these features would be useful for classifying any eukaryote? T/I

(c) Why are prokaryotic organisms more difficult to identify than eukaryotes? What characteristics must be known in order to distinguish eubacteria from Archaea? T/I A

Apply and Extend

(d) What features are shared by all forms of life? Which of these are most obvious? Which are least obvious? T/I A

(e) Life cycles can be very complex, and species can look different at different stages of the cycle. For example, gametophyte and sporophyte ferns look very different, as do caterpillars and moths. How might this make it difficult for taxonomists to classify newly discovered forms of life? T/I A

(f) Carefully examine the organism in **Figure 1**. It is a common organism in Ontario of the genus *Monotropa*. It grows out of the ground and is not photosynthetic. Predict the kingdom of this organism. Do some research to check the accuracy of your prediction. T/I A

Figure 1 This organism is of the genus *Monotropa*

(g) Which kingdom of life did you find the most interesting to study? Why? C

GO TO NELSON SCIENCE

CHAPTER 3 SUMMARY

Summary Questions

1. Create a study guide based on the Key Concepts listed at the beginning of the chapter, on page 78. Divide the guide into three parts: Fungi, Plants, and Animals. For each group, make a bulleted list of its key characteristics, its important roles in the environment, and the ways it can harm and/or benefit humans. Include a labelled sketch of a representative example from each group.
2. Look back at the Starting Points questions at the beginning of the chapter, on page 78. Answer these questions using what you have learned in this chapter. Compare your answers with those that you gave at the beginning of the chapter. How has your understanding changed? What new knowledge and skills do you have?

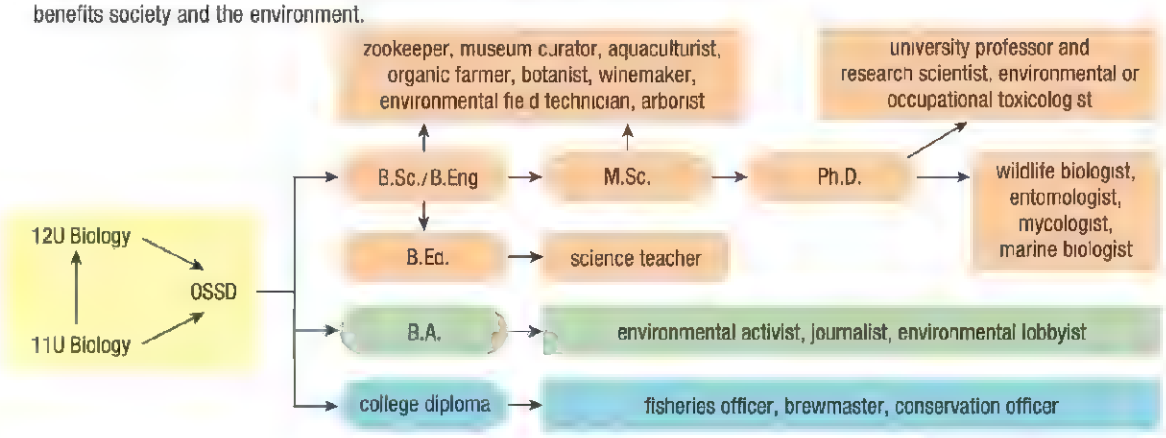
Vocabulary

mycelium (p. 82)
hypha (p. 82)
chitin (p. 82)
dikaryotic (p. 83)
meiosis (p. 83)
mycorrhiza (p. 84)
charophyte (p. 86)
cuticle (p. 89)
stoma (p. 89)
bryophyte (p. 89)
antheridium (p. 89)
archegonium (p. 89)
sporangium (p. 89)
gemma (p. 90)
lignin (p. 90)
lycophyte (p. 90)
pterophyte (p. 90)
rhizome (p. 91)
frond (p. 91)
pollen (p. 92)
ovule (p. 92)
seed (p. 92)
gymnosperm (p. 92)
cone (p. 92)
angiosperm (p. 93)
flower (p. 93)
fruit (p. 93)
cotyledon (p. 93)
radial symmetry (p. 97)
bilateral symmetry (p. 97)
protostome (p. 98)
deuterostome (p. 98)
vertebrate (p. 98)
notochord (p. 98)
invertebrate (p. 98)
germ layer (p. 98)
coelom (p. 98)
nematocyst (p. 99)
amniotic egg (p. 103)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or postgraduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

1. Select two careers related to the study of fungi, plants, and animals that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, the main duties and responsibilities, the working conditions, and the setting. Also outline how the career benefits society and the environment.



GO TO NELSON SCIENCE

CHAPTER 3 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. What are the cell walls of fungi made up of? (3.1) K/U
   (a) mycelium
   (b) chitin
   (c) hyphae
   (d) cellulose
2. The symbiotic relationship called mycorrhiza is a relationship between fungi and what? (3.1) K/U
   (a) animals
   (b) bacteria
   (c) plants
   (d) protists
3. Which of the following human diseases is caused by a fungus? (3.1) K/U
   (a) chicken pox
   (b) malaria
   (c) tuberculosis
   (d) ringworm
4. Which of the following groups of plants evolved most recently? (3.2) K/U
   (a) nonvascular plants
   (b) gymnosperms
   (c) seedless vascular plants
   (d) angiosperms
5. Which of the following characteristics best describes a bryophyte? (3.2) K/U
   (a) low to the ground
   (b) has a woody stem
   (c) lives in ecosystems with almost no moisture
   (d) produces large flowers
6. Most of the plant species that are alive today belong to which of the following groups? (3.2) K/U
   (a) gymnosperm
   (b) angiosperm
   (c) lycophyte
   (d) bryophyte
7. Which pair of characteristics could be used to describe all animals? (3.3) K/U
   (a) multicellular, heterotrophic
   (b) invertebrate, marine
   (c) eukaryotic, radial symmetry
   (d) segmented bodies, photosynthetic
8. Which of the following body systems develops from the ectoderm layer of an embryo? (3.3) K/U
   (a) circulatory system
   (b) nervous system
   (c) excretory system
   (d) muscular system
9. Animals in which of the following groups are classified as chordates? (3.3) K/U
   (a) amphibians
   (b) mollusks
   (c) nematodes
   (d) arthropods
10. Which of the following statements is true about the world's fisheries?
    (a) Many of the world's fisheries are in decline or at risk.
    (b) Some fisheries are wild, and others are farmed.
    (c) Some fisheries may be causing serious environmental damage.
    (d) all of the above

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

11. Fungi and animals are more closely related than fungi and plants. (3.1) K/U
12. Fungi carry out internal digestion to get the nutrients they need to live. (3.1) K/U
13. Each hypha in the body of a fungus has a single nucleus. (3.1) K/U
14. Plants evolved from green algae. (3.2) K/U
15. In a plant life cycle, the gametophyte stage is diploid. (3.2) K/U
16. Pollen grains contain a plant embryo and a food supply for the embryo. (3.2) K/U
17. All animals use oxygen to carry out aerobic respiration. (3.3) K/U
18. Porifera and Cnidaria are two types of vertebrate animals. (3.3) K/U
19. The waterproof amniotic egg is an example of an adaptation to a marine environment. (3.3) K/U
20. Turtles, snakes, and lizards are examples of amphibians. (3.3) K/U
21. Scientists believe that more than half of Earth's fisheries are unsustainable. (3.4) K/U

To do an online self-quiz, GO TO NELSON SCIENCE

CHAPTER 3 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. What role do fungi play in ecosystems? (3.1) K/U
   (a) producers
   (b) nitrogen fixers
   (c) decomposers
   (d) top carnivores
2. Which characteristic describes both plants and fungi? (3.1, 3.2) K/U
   (a) photosynthetic
   (b) eukaryotic
   (c) able to move
   (d) have hyphae
3. What substance is contained in large amounts in the cell walls of plants? (3.2) K/U
   (a) chitin
   (b) chlorophyll
   (c) cellulose
   (d) cotyledon
4. Which term describes a plant in the diploid stage? (3.2) K/U
   (a) sporophyte
   (b) larva
   (c) gametophyte
   (d) spore
5. Mosses, liverworts, and hornworts are all examples of what? (3.2) K/U
   (a) lycophytes
   (b) gymnosperms
   (c) bryophytes
   (d) pterophytes
6. Which of the following plant structures is the most important human food source? (3.2) K/U
   (a) roots
   (b) stems
   (c) leaves
   (d) seeds
7. Which type of organism was the most likely common ancestor of all animals? (3.3) K/U
   (a) bacteria
   (b) protist
   (c) plant
   (d) fungi

Match each term on the left with the most appropriate description on the right.

8.

(a) Arthropoda	(i) segmented bodies, jointed appendages
(b) Nematoda	(ii) segmented worms, most have bristles on body
(c) Annelida	(iii) no respiratory or circulatory system, use cilia to obtain food
(d) Mollusca	(iv) flattened unsegmented worms with no coelom
(e) Rotifera	(v) unsegmented cylindrical bodies, complete digestive tracts
(f) Platyhelminthes	(vi) have a mantle that secretes a shell (3.3) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

9. All forms of fungi form symbiotic relationships with plant roots. (3.1) K/U
10. The yeast used to make breads belong to the phylum Ascomycota. (3.1) K/U
11. Hyphae consist of long tubes, each containing one nucleus. (3.1) K/U
12. Yeast are fungi that are multicellular. (3.1) K/U
13. All plants are eukaryotic heterotrophs. (3.2) K/U
14. There are three major groups of plants. (3.2) K/U
15. In plants, vascular tissue consists of xylem and phloem. (3.2) K/U
16. The types of plants that produce cones are called gymnosperms. (3.2) K/U
17. Monocots and eudicots are two groups of mosses. (3.2) K/U
18. Most of today's plants species are angiosperms. (3.2) K/U
19. The deuterostome invertebrates occupy almost every environment on earth and include the vast majority of all animal species. (3.3) K/U
20. A bony skeleton and paired appendages are characteristics of vertebrates. (3.3) K/U
21. Lizards belong to the taxonomic group Mammalia. (3.3) K/U
22. Many different kinds of fisheries are at risk around the world, including wild tuna and salmon, wild shrimp, north Atlantic cod, and many large shark species. (3.4) K/U

Understanding

Write a short answer to each question.

23. Describe three ways that fungi negatively impact humans. (3.1) K/U T/I
24. (a) Identify three foods that humans eat that are produced using fungi.
    (b) Identify two substances used in medicine that are produced by fungi. (3.1) K/U
25. (a) Make a labelled diagram that shows the structure of hyphae.
    (b) Explain how the structure of hyphae is related to the ease of movement of materials throughout the hyphae. (3.1) K/U A
26. Identify a difference between the nuclei of the cells of fungi and the nuclei of the cells of most other eukaryotes. (3.1) K/U
27. Describe the process of external digestion in fungi. (3.1) K/U
28. A basidiomycete has a complex life cycle. The mushrooms we are familiar with are a part of this life cycle. (3.1) K/U T/I
    (a) Identify the spore-producing structures that form on the gills on the underside of a mushroom's cap.
    (b) Describe the steps in the process of spore formation that occurs in these structures.
29. Describe the process of budding, the form of reproduction found in yeast. (3.1) K/U
30. (a) Identify the organisms that make up lichen.
    (b) Classify the relationship between the organisms that make up the lichen.
    (c) Summarize the role of each of the organisms that makes up lichen.
    (d) Predict what would happen if one of the organisms that makes up lichen died. Explain your prediction. (3.1) K/U T/I
31. (a) Identify the two types of organisms that are involved in a relationship called mycorrhiza.
    (b) Classify the relationship between the organisms.
    (c) Summarize how each of the organisms is affected by this relationship. (3.1) K/U
32. Use the information in this section to explain why people keep many types of food in the refrigerator rather than at room temperature. (3.1) K/U A
33. Provide examples of each of the following:
    (a) how plants benefit animals
    (b) how fungi benefit plants
    (c) how fungi benefit animals (3.2) K/U
34. Many types of plants on Earth, including some of those found in Ontario, are threatened. (3.2) K/U T/I
    (a) Identify four major factors that threaten plant life.
    (b) Predict and describe two specific consequences of a decrease in the number of plants on Earth.
35. There is strong evidence that plants evolved from charophytes, a group of green algae. Describe the similarities between plants and charophytes that provide evidence for this evolutionary relationship. (3.2) K/U
36. Sequence the following plant characteristics in the order in which they evolved in plants. (3.2) K/U T/I
    - flowers
    - vascular tissue
    - seeds
37. Wind-pollinated flowers are usually small and green and have little or no odour. Why are colour and fragrance unnecessary for these flowers? Brainstorm a possible advantage these features give to the plant. (3.2) K/U A
38. Copy **Table 1** into your notebook and use it to classify the following parts of a plant life cycle: sex cells, sporophyte, gametophyte, zygote, and spores. (3.2) K/U

Table 1 Plant Life Cycle

Haploid (n)	Diploid ($2n$)

39. You observe a green moss plant on the forest floor. Identify the stage in the moss's life cycle you are seeing. (3.2) K/U
40. Describe a plant's life cycle by naming the items and events that are occurring at each letter in **Figure 1**. (3.2) K/U

Figure 1 The life cycle of a fern

41. (a) Identify the chemical component of vascular tissue that most contributes to the strength of woody tissues.
    (b) Explain how the evolution of vascular tissue affected the height to which plants can grow. (3.2) K/U A
42. Today, gymnosperms and angiosperms are the dominant plants on land. (3.2) K/U T/I
    (a) Describe how the mode of movement of the male gametophytes of gymnosperms and angiosperms differs from that of other plants.
    (b) Explain how this difference has led to the dominance of these types of plants in terrestrial ecosystems.
43. Examine the interaction in **Figure 2**. Explain how this symbiotic relationship benefits both species and how it illustrates a major plant adaptation for life on land. (3.2) K/U T/I A

Figure 2 A bee on a globe thistle plant

44. The structure of gymnosperm leaves is an adaptation that contributes to the success of gymnosperms in the environment in which they live. (3.2) K/U T/I A
    (a) Describe the structure of gymnosperm leaves.
    (b) How does the structure of gymnosperm leaves help the plants survive in dry ecosystems?
45. Describe two ways that humans use gymnosperms. (3.2) K/U
46. Flowers and fruits are extremely diverse. The characteristics of flowers and fruits have evolved based on the method by which the flower is pollinated or the seed is dispersed. (3.2) K/U T/I
    (a) Explain how a flower that is plain, not brightly coloured, and not fragrant, is pollinated.
    (b) Infer how a seed that is enclosed in a juicy, sweet fruit is spread. Explain the reasoning you used to make your inference.
47. List, in order, the adaptations of plants for life on land, from earliest to most recent. Include the following adaptations in your list: flowers, waxy cuticle and stomata, vascular tissue, and seeds. (3.2) K/U
48. (a) Identify a group of animals with bodies that do not display any form of symmetry.
    (b) Describe radial symmetry. Identify a group of animals with radial symmetry.
    (c) Describe bilateral symmetry. Identify two major groups of animals with bilateral symmetry. (3.3) K/U
49. (a) Define the term "germ layers."
    (b) Identify the three germ layers found in a developing vertebrate embryo.
    (c) Describe the specialized tissues that arise from each of the germ layers. (3.3) K/U
50. Porifera are some of the simplest animals. Their characteristics distinguish them from animals in other groups. (3.3) K/U
    (a) Describe the body plan of sponges.
    (b) Describe how sponges reproduce.
    (c) Give two reasons why you would never expect to find a terrestrial species of sponges.
51. An alternation of generations life cycle is very unlike a typical animal life cycle. Compare and contrast these life cycles in terms of the following: (3.2, 3.3) K/U
    (a) the function of the cells produced by meiosis
    (b) the number of multicellular stages and their chromosome number (haploid or diploid)
    (c) the presence or absence of asexual reproduction within the life cycle
52. Identify three animal species that are vectors of disease. (3.3) K/U
53. Heartworms are animals that are parasites of other animals. Many people are familiar with heartworms because they can affect pet dogs. (3.3) K/U T/I
    (a) Identify the phylum to which heartworms belong.
    (b) Summarize the characteristics of the organisms in this phylum.
54. Describe how the symmetry of the body of an echinoderm changes as the organism grows and develops. (3.3) K/U
55. How did the development of internal supporting skeletons help chordates conquer the land? (3.3) K/U T/I
56. Describe the structure of an amniotic egg and explain how amniotic eggs are related to success in a terrestrial environment. (3.3) K/U T/I

57. Sequence the evolution of the following chordate characteristics, from the earliest to most recent. (3.3) K/U T/I
    - bony skeleton
    - two pairs of limbs
    - notochord
    - true vertebrae
    - amniotic eggs
58. Humans are just one of many species of animals. (3.3) T/I A
    (a) Identify two characteristics that humans share with sponges.
    (b) Identify four characteristics humans share with squid.
    (c) Identify six characteristics humans share with reptiles.
    (d) Identify two characteristics found only in humans and other mammals.
59. What is one advantage of an internal skeleton over an external skeleton? (3.3) K/U T/I
60. For each of the following features,
    (i) List the major vertebrate groups that possess the feature.
    (ii) Explain how the feature provides an advantage to the group(s).
    (a) enlarged brain within a cranium or skull
    (b) paired limbs
    (c) warm-blooded (3.3) K/U T/I

Analysis and Application

61. Compare the following characteristics of plants and fungi:
    (a) ability to move
    (b) cell structure
    (c) energy source (3.1) K/U T/I
62. (a) Describe the range in size of the organisms classified as fungi.
    (b) Is this range of sizes greater or less than the range of sizes of plants and animals? How do you know? (3.1) T/I A
63. Could the process of ecological succession on bare rocks occur in the absence of fungi? Explain why or why not. (3.1) T/I A
64. The law of conservation of matter states that matter cannot be created or destroyed, but it can change form. Explain how the action of fungi in ecosystems is related to this scientific law. (3.1) A
65. Athlete's foot is an example of a fungal disease. Apply what you know about fungi to describe the flow of nutrients and energy between the athlete's foot fungus and the human it has infected. (3.1) T/I A
66. As you are hiking though the woods, you notice a log on the ground, covered with mushrooms. (3.1) T/I A
    (a) Describe the feeding relationship between the log and the mushrooms.
    (b) Predict one short-term and one long-term consequence for the forest ecosystem if the entire forest was affected by a spill of a substance that was a strong fungicide.
67. The five major phyla of fungi are Chytridiomycota, Zygomycota, Glomeromycota, Ascomycota, and Basidiomycota. Look closely at these names. Using this information, what do you infer is the meaning of the term "mycotoxin"? (3.1) A
68. From a plant's point of view, identify two advantages that a terrestrial ecosystem offers when compared to an aquatic ecosystem. (3.2) A
69. Imagine that you need to label four samples of plants, one from each major plant group. (3.2) T/I A
    (a) List the four labels you will need.
    (b) You have samples of the following plants:
    - a rose plant
    - a sphagnum moss plant
    - a tree fern plant
    - a spruce tree

    Identify the label that corresponds to each of these samples.
    (c) Identify one unique characteristic of each group of plants.
70. A drought, or a long period of extreme dryness, presents challenges for all living things. In what specific way would an extended drought affect bryophytes but not other plants? Explain your response. (3.2) A
71. The gametophyte stage of lycophytes is found underground and is not photosynthetic. Could these plants survive in soil that was treated to remove all fungi? Explain. (3.2) A
72. Explain how the ability of seeds to remain dormant for long periods of time is related to the success of plants in terrestrial ecosystems. (3.2) T/I A
73. A student placed five seeds in a Petri dish with a damp paper towel and placed it in the dark. She was surprised to see that four of the seeds in the Petri dish germinated. She thought that that plants needed to carry out photosynthesis to get the nutrients and energy that they need. Based on what you know about seeds, explain why seeds can germinate in the dark. (3.2) T/I A

74. Compare and contrast flowers and cones. (3.2) T/I

75. Humans tend to select flowers with bright and fragrant flowers for their gardens. How does this affect the living things that they will find in or near their gardens? (3.2) T/I A

76. There are 34 identified biodiversity hotspots on Earth. (3.2) K/U A
    (a) Identify the two criteria used to classify an area as a biodiversity hotspot.
    (b) How does the identification of biodiversity hotspots aid in the conservation of plant species?

77. Explain how a bicycle wheel and a tennis racquet could be used to illustrate the concepts of radial symmetry and bilateral symmetry in animals. (3.3) T/I A

78. Apply what you have learned in this chapter to explain why you are unlikely to find any of the following on Earth. Give specific reasons in each response. (3.1, 3.2, 3.3) T/I A
    (a) an ecosystem that contains plants and animals, but no fungi
    (b) a terrestrial ecosystem that contains animals and fungi, but no plants
    (c) an ecosystem that contains fungi and plants, but no animals

79. Your friend must dress nicely for an interview for a summer job. She selects a silk blouse and a pearl bracelet as parts of her outfit. (3.3) K/U A
    (a) Identify the organism that produced the silk used to make the silk blouse.
    (b) To what phylum does this organism belong?
    (c) Identify the organism that produced the pearls used to make the pearl bracelet.
    (d) To what phylum does this organism belong?
    (e) Identify the group of animals into which both of these phyla are classified.

80. Echinoderms—the group that includes starfish—and chordates—the group that includes humans—seem very different. Both are classified as deuterostomes. Explain why these two very different groups share this classification. (3.3) T/I A

81. Explain how a consistent internal temperature, the ability to prevent water loss, and a bony skeleton each help organisms live in a terrestrial environment. (3.3) T/I A

Evaluation

82. You have read about aquatic and terrestrial living things, and the adaptations of living things found in each environment. In which type of environment do you think it is more difficult for living things to survive? Write a paragraph that supports your choice. (3.1, 3.2, 3.3) T/I C A

83. Although people have been classifying living things for hundreds of years, it was not until 1969 that the fungi were classified into a separate kingdom. What characteristics of fungi do you think led to this very recent classification into their own kingdom? (3.1) T/I A

84. Do you think the term "alternation of generations" is a useful term to describe the life cycle of plants? If so, give a detailed explanation that supports the use of this term to describe the life cycle of plants. If not, suggest a term or phrase you think better describes the life cycle of plants, and write a detailed explanation supporting your suggestion. (3.2) T/I C A

85. Many of the world's plants are threatened species. Think about the factors that threaten plants. Use that information to answer the questions below. (3.2) T/I A
    (a) Do you feel that insects or humans are a greater threat to plants?
    (b) Explain and support your response to (a).

Reflect on Your Learning

86. After reading about the great variety of animals on Earth, select one type of animal you would enjoy having as a pet. Identify the animal, and describe how it is classified. Then list the unique characteristics this type of animal has. K/U A

87 The vertebrates are the most complex of all organisms, yet they are far outnumbered by the invertebrate animals. Which group would you consider most successful? Why? T/I

88. Based on the information in this chapter, what do you think is the biggest threat to biodiversity? What actions are you taking, or could you take, to help preserve biodiversity? K/U T/I A

89. The vast majority of animals are invertebrates (**Figure 3**). Has learning about the great variety of living things classified as animals changed your perception of this kingdom of living things? Explain why or why not. K/U A

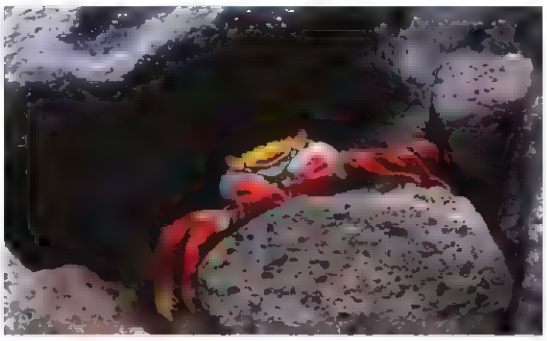


Figure 3 A Sally lightfoot crab

90. When people learn about food chains, food webs, and competition for resources in ecosystems, they typically do not think about humans as a part of these interactions. After all, when we are hungry, we can simply go to the grocery store to buy food. This chapter reminds us that humans and insects are in fierce competition for many of the foods we rely on. How does this information change the way you think about the food you buy at the store? T/I C A

Research

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91. One of the most important ways yeast is used by humans is in the production of bread. Research to learn more about the role that yeast plays in bread production. Write a paragraph that explains this process. Then do additional research to learn more about different types of bread that use yeast. Select one recipe to copy and share with your classmates. T/I C A
92. Fungi have had an enormous impact on human healthcare. The discovery of penicillin and cyclosporine changed the way that many human diseases are treated. Research penicillin and cyclosporine, medications made using fungi. Find out how they are manufactured and for what conditions they are used. Prepare a report to share what you have learned with your classmates. T/I C A
93. Fungi can grow inside of homes and may release toxic substances. Homes and building affected by these fungi may be hazardous for people to live in. Research to find out more about the types of hazardous fungi that are found in homes and the health impacts on people who lived in affected homes. Prepare a pamphlet to share what you have learned. T/I C A
94. Research and make a poster describing endangered and extirpated plants in Ontario. Your poster should identify two species in each category. Find out about regulations that protect these plants and include that information on your poster. Be sure to include both text and illustrations on your poster. T/I C A
95. You have read about the role of seeds and fruit in the reproduction of plants. However, many of the fruits we buy as food products are "seedless." For example, seedless grapes and seedless oranges are much more popular than the varieties with seeds. Research to find out how seedless fruit is produced. T/I C A
96. Natural sea sponges are used by people for cleaning. Research to learn more about sea sponges. Find out where the sponges grow, how they are harvested, and whether or not the harvesting of sea sponges is done in a sustainable way. Prepare a short report to share what you have learned. T/I C A
97. One way that humans depend on other animals is to pollinate the food crops we depend on. Insects, including bees, are some of the most important pollinators of food crops. Recently, there has been a great deal of concern about the declining population of bees. The term "colony collapse disorder" has been used to describe this situation. Research to learn more about colony collapse disorder and its potential economic impact. Write a short newspaper-style article to share what you have learned. T/I C A
98. The emerald ash borer is an invasive species of insect that has a devastating impact on ash trees. Research the interaction between these two species. Then find out what is being done in Ontario to limit the spread of the emerald ash borer. Prepare a poster to share what you have learned with others in your class. T/I C A
99. Ontario's beech trees (*Fagus grandifolia*) are an important food source for many species of wildlife. For example, black bears climb the trees to feed on the beech nuts in the fall (**Figure 4**). These trees are now under serious threat from a fungal disease that is spread by a small insect.
    (a) Research the origin of this disease and how it is spread.
    (b) How might the loss of beech trees affect other species, including bears?
    (c) What, if anything, can be done to reduce the impact of this disease? T/I C A

Figure 4 A bear climbed this beech tree in Ontario to harvest beech nuts, leaving these claw marks.

UNIT 1 UNIT TASK

Diversity at Risk

The United Nations declared 2010 the International Year of Biodiversity. The United Nations hoped to draw attention to the threats to Earth's biodiversity and to create opportunities for increasing people's understanding of the vital role biodiversity plays in sustaining life on Earth.

Biodiversity is vital for supporting the living systems that provide us with our food, fuel, health, and wealth. Human activity is now seriously threatening biodiversity, resulting in the irreversible loss of species and potentially irreparable damage to ecosystems.

In this Unit Task you will select a group of living organisms and examine the roles they play in supporting ecosystems. You will investigate specific threats to their diversity by examining how human actions are influencing the group in negative and positive ways.

Purpose

To investigate the current status of a selected group of organisms, examine how their diversity supports ecosystems, assess any threats to their diversity, and research any actions being taken to protect them

Procedure

Part A: Select and Assess a Group

1. First select a particular *phylogenetic group* of organisms. You can select a large or a small group. You may also limit your investigation to a particular region. For example, you could study flowering plants of Ontario, Arctic whale species, or all wild members of the Felidae (the cat family). Get approval from your teacher before continuing.
2. Research your chosen group and compile information about the following:
   (a) The basic biology of the group: Describe the unifying characteristics of the group. Include a labelled diagram of a representative species and a description of its life cycle.
   (b) The diversity of the group: Describe the estimated number of species, the range of ecosystems they inhabit, and the diversity of characteristics within the group, and include a phylogenetic tree of the group.
   (c) The roles of the group in supporting ecosystems. Describe their ecological niches and ways in which other species are dependent on them.
3. If possible, directly observe and document members of the group (**Figure 1**). You may have members of the group in your local environment or on display in zoos or natural history museums. If you cannot observe members of the group directly, use the Internet and other sources to view still and video images of them.

Figure 1 Barn owls are endangered in Ontario and throughout Canada.

Part B: Assess the Group's "At Risk" Status

4. Use the Internet and other available resources to assess the current status of your group. Do all species within the group have healthy populations, or are some or all of them at risk?

5. Describe threats to members of the group. If there are many threats, provide an assessment of the ones you think are most important (**Figure 2**). Are the threats increasing or decreasing?

   Note: the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species is the most comprehensive global database for this information.

Figure 2 (a) Habitat destruction is a negative way that humans affect biodiversity. (b) Conservation efforts, such as the use of boardwalks, can reduce human impact on ecosystems and protect biodiversity.

Part C: Conservation in Action

6. Find out what actions are being taken by organizations to help protect the entire group or individual species. Evaluate these actions. Are they effective? Can these organizations have a significant long-term impact on the future of the group?
7. Describe ways that individuals can become involved in protecting the diversity of the group.
8. Use the Internet and other sources to learn about the International Convention of Biological Diversity and the Youth Accord for Biodiversity. Who was involved? What were their objectives?

Analyze and Evaluate

9. Prepare a report of your investigations and findings Your report can be divided into the following components:
   (a) Abstract: a short, one-paragraph summary of the entire investigation
   (b) Introduction: a brief overview of the importance of diversity in general to the health of ecosystems
   (c) Parts A to C: sections corresponding to the parts of the procedure
   (d) Discussion: concluding remarks that include your assessment of the importance and status of your group and their long-term outlook, as well as some thoughts on the global status of biodiversity T/I C A

Apply and Extend

10. Exchange reports with several classmates and read theirs.
    (a) Compare the threats to your group with those to other groups. Suggest reasons for the similarities and differences. T/I C A
    (b) Were the same organizations involved in protecting more than one group of organisms? K/U
    (c) Did the major conservation organizations you researched spend most of their efforts on the protection of specific groups, specific species, or specific habitats? Why do you think they made these choices? T/I A

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ASSESSMENT CHECKLIST

Your completed Performance Task will be assessed using the following criteria:

Knowledge/Understanding

- ✓ your understanding of the unifying characteristics of your group
- ✓ your depiction of the life cycle of your representative species
- ✓ your understanding of the ecological relationships between species in your group and other organisms

Thinking/Investigation

- ✓ your ability to find and select relevant information
- ✓ your ability to synthesize information from a variety of sources
- ✓ your ability to evaluate the accuracy and currency of information from various sources
- ✓ the evidence on which you judge the threats to the group

Communication

- ✓ the organization and clarity of the information in your final report
- ✓ the effectiveness of your written presentation
- ✓ your use of appropriate visuals to support your findings and conclusions

Application

- ✓ the quality of your assessment of the threats to your group and of conservation efforts and options
- ✓ your understanding of the importance of biodiversity in supporting the sustainability of ecosystems

UNIT 1 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which of the following is another name for biologically inherited information? (1.1) K/U
   (a) evolutionary information
   (b) genetic information
   (c) morphologic information
   (d) behavioural information
2. The physical and behavioural changes that occur in an entire population over time are referred to as
   (a) hybridization
   (b) structural changes
   (c) genetic changes
   (d) evolutionary changes (1.1) K/U
3. Which of the following is the highest taxonomic level of the traditional Linnaean system of classification? (1.2) K/U
   (a) phylum
   (b) species
   (c) class
   (d) kingdom
4. How are species grouped in a phylogenetic tree? (1.3) K/U
   (a) into families
   (b) into clades
   (c) into classes
   (d) into orders
5. Fungi and animals have which of the following in common? (1.4) K/U
   (a) Both have eukaryotic cells.
   (b) Both only reproduce sexually.
   (c) Both have cells with chloroplasts.
   (d) Neither are heterotrophic.
6. Modern classification systems are based on which of the following? (1.4) K/U
   (a) six kingdoms and three domains
   (b) three kingdoms and six domains
   (c) six kingdoms and six domains
   (d) three kingdoms and three domains
7. Which of the following is true of crocodilians? (1.5) K/U
   (a) They are the only reptiles with dinosaur ancestry.
   (b) They are the only reptiles with four-chambered hearts.
   (c) They are the only egg-laying reptiles.
   (d) all of the above
8. Infectious bacteria, which are responsible for millions of human deaths each year, are called
   (a) pathogens
   (b) antibiotics
   (c) endospores
   (d) organelles (2.1) K/U
9. Which of the following is true of all organic chemicals? (2.1) K/U
   (a) They all have an abiotic origin.
   (b) They all contain carbon.
   (c) None are produced by living things.
   (d) all of the above
10. What is a virus that infects bacteria cells called?
    (a) a viroid
    (b) a prion
    (c) a capsid
    (d) a bacteriophage (2.2) K/U
11. What is the process by which a virus enters a host cell, replicates, and destroys the host cell? (2.2) K/U
    (a) an epidemic
    (b) a pandemic
    (c) an infectious cycle
    (d) a transduction
12. What is the seaweed wrap used in sushi? (2.3) K/U
    (a) *Giardia lamblia*
    (b) *Parmecium*
    (c) *Euglena*
    (d) *Porphyra*
13. Which of the following is true of a zygote? (2.3) K/U
    (a) It is formed by the fusion of four sex cells.
    (b) It is diploid.
    (c) It is haploid.
    (d) It is a spore.
14. Which of the following careers involves diagnosing and treating diseases in trees? (3.1) K/U
    (a) arborist
    (b) botanist
    (c) taxonomist
    (d) geneticist
15. Which of the following dominates most of the land on Earth? (3.2) K/U
    (a) mammals
    (b) insects
    (c) fungi
    (d) plants

16. Which of the following is true of all plants? (3.2) K/U
    (a) They are multicellular.
    (b) They are eukaryotic.
    (c) They are sessile.
    (d) all of the above
17. Which is the only animal with a body that lacks any true symmetry? (3.3) K/U
    (a) human
    (b) whale
    (c) sponge
    (d) snake
18. Which of the following describes the great majority of animal species? (3.3) K/U
    (a) bilaterally symmetrical
    (b) vertebrates
    (c) invertebrates
    (d) protostomes

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

19. Although entire populations can and do change over time, they do not change over space. (1.1) K/U
20. The greatest species diversity exists in ecosystems with many different species that each have large populations. (1.1) K/U
21. The best criteria to use for classifying organisms depend on the purpose of the classification system. (1.2) K/U
22. Many animals of direct interest to humans are relatively easy to identify, but the same is *not* true of plants. (1.2) K/U
23. Clades include only a small number of species that share a very recent common ancestor. (1.3) K/U
24. The Linnaean classification system recognized only two kingdoms of living things—Animals and Plants. (1.4) K/U
25. All feathered dinosaur species had the ability to fly. (1.5) K/U
26. Scientists believe that they have identified more than half of the total number of species of prokaryotes. (2.1) K/U
27. Fossil evidence shows that prokaryotes have lived on Earth for more than 3.5 billion years. (2.1) K/U
28. Although epidemics are large-scale outbreaks of a disease, they are usually confined to a limited geographic region. (2.2) K/U
29. Pandemics are usually smaller in scale and global impact than epidemics. (2.2) K/U
30. Although protists play key roles in ecosystems on land, their role is diminished in the oceans. (2.3) K/U
31. The only characteristic that all protists share is that they are not animals, plants, or fungi. (2.3) K/U
32. Along with bacteria, fungi are the major decomposers on Earth. They are responsible for much of the cycling of nutrients through the biosphere. (3.1) K/U
33. Fungi are not plants. (3.1) K/U
34. Most plant species are aquatic and live in Earth's oceans. (3.2) K/U
35. The bryophytes are the simplest of land plants. (3.2) K/U
36. Seed plants are restricted to reproduction over small distances and in wet conditions. (3.2) K/U
37. One thing that most animals have in common with plants and fungi is that they are sessile. (3.3) K/U
38. The common ancestor of all animals was likely a colonial, flagellated protist that lived 700 million years ago. (3.3) K/U
39. Mammals, fish, amphibians, reptiles, and birds are all vertebrates. (3.3) K/U

To do an online self-quiz,
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UNIT 1 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. Which of the following is true of organisms that reproduce asexually? (1.1) K/U
   (a) They often undergo hybridization.
   (b) They make up the majority of all organisms.
   (c) They do not fall under any of the six kingdoms.
   (d) The species definition does not apply to them.
2. Which of the following shows the correct descending order of taxonomic levels in the traditional taxonomic ranks of classification? (1.2) K/U
   (a) kingdom, class, family, species
   (b) kingdom, species, family, class
   (c) species, family, class, kingdom
   (d) species, kingdom, class, family
3. Who authored *On the Origin of Species*? (1.3) K/U
   (a) Carl Woese
   (b) Carl Linnaeus
   (c) Charles Darwin
   (d) none of the above
4. Which of the following is true of Carl Woese's work? (1.4) K/U
   (a) He was the first to identify the six kingdoms of life.
   (b) He revealed that all organisms could be classified into three distinct groups, called domains.
   (c) He established the two-part naming system called binomial nomenclature.
   (d) He placed all organisms into two kingdoms: Plants and Animals.
5. Which of the following is a reason to place birds into a class of their own? (1.5) K/U A
   (a) Birds are among the most easily distinguished of all animals.
   (b) Birds are covered in feathers and have powerful wings and beaks.
   (c) Unlike most other vertebrates, birds lay hard-shelled eggs.
   (d) all of the above
6. What is an inorganic chemical? (2.1) K/U
   (a) any chemical that contains carbon
   (b) any chemical that is produced by living things
   (c) a chemical that has an abiotic origin
   (d) all of the above
7. Which of the following is the best example of a pandemic? (2.2) K/U A
   (a) a season during which various viruses coexist in many different regions
   (b) an outbreak of one disease affecting an entire Canadian school district
   (c) an outbreak of one disease over many countries and continents
   (d) a disease that recurs in one defined area or region annually
8. In which of the following is seaweed, a multicellular protist, commonly used? (2.3) K/U
   (a) fertilizers
   (b) toothpastes
   (c) cosmetics
   (d) all of the above
9. What are you eating every time you eat a mushroom or a truffle? (3.1) K/U A
   (a) abiotic plants
   (b) fungi
   (c) sessile animals
   (d) aquatic organisms
10. Which of the following is true of plants? (3.2) K/U
    (a) Plants can survive in many different climatic conditions.
    (b) Because of their natural resistance, virtually none of the world's plants are threatened.
    (c) Plants share no characteristics with green algae.
    (d) Most plant species today live in aquatic ecosystems.
11. Which of the following is the name given to animals that do *not* have backbones or notochords? (3.3) K/U
    (a) invertebrates
    (b) vertebrates
    (c) chordates
    (d) amphibians
12. Which of the following groups do humans belong to? (3.3) K/U
    (a) invertebrates
    (b) chordates
    (c) echinoderms
    (d) protostomes

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

13. Most biologists define a species as a group whose members are able to freely breed among themselves under natural conditions. (1.1) K/U

14. Taxonomists use systems of classification in their daily work, but botanists find little use for classification systems. (1.2) K/U
15. Taxonomists today rely on only one proven method for classifying organisms. (1.3) K/U
16. Plants and fungi each belong to distinct kingdoms. (1.4) K/U
17. Bacteria are essential in the production of foods such as cheeses, yogurt, soy sauce, and chocolate. (2.1) K/U
18. Viruses are small, living particles. (2.2) K/U
19. Viruses cannot reproduce without a host cell. (2.2) K/U
20. Although protists are abundant, the Protist Kingdom is not very diverse. (2.3) K/U
21. One thing all fungi have in common is that they are helpful to other organisms. (3.1) K/U
22. Plants are thought to have evolved from charophytes, a group of green algae. (3.2) K/U
23. Jellyfish are an example of an animal species that has radial symmetry. (3.3) K/U
24. Like plants and fungi, animal cells have cell walls. (3.3) K/U

Write a short answer to each question.

25. Species can evolve, or change, over many generations. What is the other natural means by which species can change or evolve? (1.1) K/U
26. Why are plants considered autotrophs? (1.1) K/U
27. What is the classic example of the use of a classification system in chemistry? (1.2) K/U A
28. Swedish naturalist Carl Linnaeus introduced a consistent way of grouping species. What did he base the groupings on? (1.2) K/U
29. What is the main difference between the traditional classification system and modern biological classification? (1.3) K/U A
30. Name the six kingdoms of life. (1.4) K/U
31. Evidence suggests a strong evolutionary connection between birds and which two unlikely groups of organisms? (1.5) K/U
32. What produces natural antibiotics? (2.1) K/U
33. What is an obligate aerobe? (2.1) K/U
34. Although viruses are non-living particles, they do share one important trait with living things. What is this shared trait? (2.2) K/U
35. Viruses do not carry out life functions like living cells do. When, then, do viruses become active? (2.2) K/U
36. Only five of the six kingdoms are based on evolutionary kinship. Name them, and identify the one that is not. (2.3) K/U
37. What is the difference between a haploid cell and a diploid cell? (2.3) K/U T/I
38. What do fungi and plants have in common? (3.1) K/U T/I
39. What are lichens? (3.1) K/U
40. Describe some current threats to the world's plants. (3.2) K/U
41. Why must land plants be able to take in small amounts of carbon dioxide gas from the atmosphere? (3.2) K/U
42. In what way do the bodies of animals with radial symmetry differ from the bodies of animals with bilateral symmetry? (3.3) K/U
43. What are the simplest invertebrates? (3.3) K/U

Understanding

44. In order to assess the diversity of life, scientists must observe and accurately describe each kind of living thing. With millions of different kinds of organisms, this is a complicated task. What is the first step for scientists in describing each kind of living thing? (1.1) K/U T/I
45. Over millions of years it is not uncommon for species to experience evolutionary change. Name and describe an example of a species that you feel has not undergone significant evolutionary change. Why do you think this species' characteristics have remained basically unchanged for so long? (1.1) K/U
46. Different species vary in their behaviours, habits, ecological niches, and abundance. They also vary in their genetic makeup, referred to as genetic diversity. (1.1) K/U
    (a) In humans, where does our genetic information come from?
    (b) What evidence do you have that your genetic information comes from this source?
47. Heterotrophs and autotrophs are very different types of organisms. Plants are examples of autotrophs. (1.1) K/U
    (a) Define what makes an organism a heterotroph.
    (b) Give one example of a heterotroph. Explain how you know this organism is a heterotroph.
48. Briefly describe what you think a typical workday in the life of a botanist might involve. What types of organisms might he or she study? What system or systems of classification might he or she use? (1.2) K/U A

49. Carl Linnaeus was among the first prominent biologists to doubt the "fixed" nature of species. He theorized that new species might arise over time. In your own words, describe how a new species might arise. (1.2) T/I

50. Choose three species, two that are somewhat closely related and one that is more distantly related to the other two. Using a phylogenetic tree, illustrate the relationship between the three species. (1.3) T/I

51. Using clades of animals in one diagram and your family members in another, demonstrate how a phylogenetic tree is similar to a family tree. (1.3) T/I

52. In 1859, Charles Darwin published *On the Origin of Species*, in which he described his theory of evolution. Using a simplified phylogenetic tree, illustrate the basic principle of Darwin's theory. (1.3) T/I

53. Plants and fungi belong to different kingdoms. List some facts that support this classification. (1.4) T/I A

54. Copy **Table 1** into your notebook. Then identify all six kingdoms and list one example for each. (1.4) T/I A

Table 1

Kingdom	Example

55. Scientists believe that birds are closely related to dinosaurs and modern crocodiles. (1.5) T/I
    (a) Discuss the evidence that supports this theory.
    (b) Demonstrate how this evidence links modern-day crocodiles to the ancient dinosaurs.

56. Despite their incredibly small size, prokaryotes are dominant forms of life. Describe why, despite their small size, these organisms are so dominant. (2.1) T/I

57. Prokaryotes are extremely important organisms in many positive ways. (2.1) T/I
    (a) Explain how they are important in ecosystems.
    (b) Identify two examples of how prokaryotes are important to humans in a positive way.

58. Prokaryotes are extremely important organisms in many negative ways. (2.1) T/I
    (a) Explain how they are important in ecosystems in negative ways.
    (b) Identify two examples of how prokaryotes are important to humans in a negative way.

59 What are antibiotics? Why are they so important to humans? (2.1) K/U A

60. Viruses are small, non-living particles. How, then, are they able to be so harmful and destructive? (2.2) K/U

61. Viruses are responsible for many human diseases and, therefore, are often thought of only in a negative way. Viruses can, however, also be used in positive ways. Discuss one positive way in which viruses can be used. (2.2) K/U A

62. Choose one virus about which you have some knowledge and discuss its effects on the human body. (2.2) K/U

63. Some protists have the ability to cause serious disease, but many are valuable to humans. Give two examples of protists that are valuable or useful to humans and describe what makes them so. (2.3) K/U

64. Describe what makes the Protist Kingdom different from the other five kingdoms. (2.3) K/U

65. Fungi have more in common with animals than they do with plants. (3.1) K/U T/I
    (a) Explain how fungi and plants are different.
    (b) Describe what fungi have in common with animals.

66. A cousin of the mushroom, truffles, are among the most expensive foods humans consume. Explain why you think these fungi are so precious and expensive. (3.1) T/I

67. Explain how fungi are able to reproduce so effectively and so abundantly. (3.1) T/I

68. Plants can survive in many different climates. They have different characteristics that help them succeed in their particular habitats. (3.2) T/I
    (a) Identify a plant you know of that survives in an extreme climate.
    (b) How do you think this plant is able to succeed in this extreme climate?
    (c) Explain why you think this plant could or could not succeed in a much different climate.

69. The primitive ancestors of today's plants lived in the water. When plants first began to live on land, they developed characteristics that allowed them to live and reproduce in that new environment. (3.2) K/U
    (a) What was the first requirement for life on land?
    (b) How did plants adapt to accomplish this?

70. Though land plants have created a diversity of living habitats and food sources for countless terrestrial animals, including humans, this diversity is threatened by human actions. (3.2) K/U T/I
    (a) What is the most widespread threat to plant life on Earth today?
    (b) How has this threat worsened over the years, and what have some of the consequences been?
71. Describe how a jellyfish would look if it had bilateral symmetry instead of radial symmetry. (3.3) T/I
72. The protostomes include many species that are of great importance to humans and interact with us in direct ways. Give an example of each of the following, and describe how it affects us. (3.3) T/I
    (a) a protostome that affects our food supply
    (b) a protostome that affects our health
    (c) a protostome that affects our economy
73. Explain what the development of an amniotic egg did for vertebrates, and describe what that has evolved into for today's mammals. (3.3) T/I
74. The world's marine ecosystems provide humans with a rich supply of high-quality foods. Unfortunately, this supply of food has been adversely affected by a number of factors over the years. (3.4) T/I
    (a) Identify one way in which supplies of marine foods have been affected.
    (b) Discuss a potential solution.

Analysis and Application

75. Make a clear distinction between individual variability and evolutionary change. You are very different from many of your classmates, but you are also very different from someone who lived 20 000 years ago, from whom you are directly descended. Examine both individual variability and evolutionary change, and explain how they are different. (1.1) T/I A
76. Evolutionary changes usually occur over long periods of time and over long distances. Many species today have very different characteristics compared with the same species several thousand years ago. And, similarly, many species living across far-reaching places on Earth have different characteristics, depending on the climate and region in which they live. (1.1) K/U T/I A
    (a) Giving examples of both, distinguish between these two different types of evolutionary change.
    (b) Explain how the cause for change in a species over a long period of time could also be the cause for a change over great distances and different climates.
77. Although many new species are discovered each year, biologists fear that the diversity of life is declining rapidly. The loss of biodiversity affects humans in many ways. (1.1) T/I A
    (a) Describe one case of declining biodiversity.
    (b) How has this specific loss of biodiversity affected humans?
78. Classification systems are extremely useful. By using the same classification systems, scientists can share ideas more easily. Imagine a world without classification systems. (1.2) T/I A
    (a) How might our knowledge of organisms and species be affected?
    (b) Choose a part of your life that would be very different, and explain how it would be different.
79. A key challenge that traditional taxonomists face is deciding and agreeing on what criteria to use to define each taxon. (1.2) T/I A
    (a) Establish a set of criteria for a familiar taxon.
    (b) What features will be used to base a decision on whether or not to include organisms in it?
80. Marine biologists and botanists both study organisms, but they have very different jobs. Which job would you rather have? Citing job responsibilities, explain why. (1.2) K/U T/I A
81. Phylogeny is the science that deals with evolutionary relationships between and among species. These relationships can be presented in a phylogenetic tree. Refer to the phylogenetic tree in **Figure 1** to answer the following questions. (1.3) K/U T/I A
    (a) What is incorrect about the relationships shown by the branches of the tree?
    (b) Correctly restructure the branches.
    (c) Hypothesize why some of the species are considered more closely related to each other.

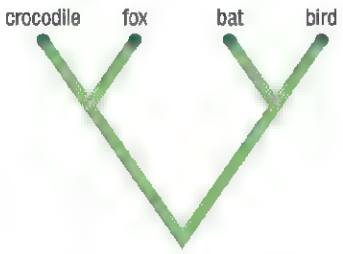


Figure 1 An incorrect phylogenetic tree for bird, fox, bat, and crocodile

82. In 1996, Carl Woese used a detailed analysis of living organisms to uncover some relationships between the six kingdoms of life. (1.4) T/I A
    (a) Compare and contrast Woese's findings with those of Carl Linnaeus.
    (b) Though the two had different ideas, explain how their theories complement each other.
83. Draw a phylogenetic tree that shows the key evolutionary relationships of the six kingdoms. (1.4) K/U C
84. Birds are thought to be the descendants of dinosaurs because of the many characteristics the two groups share. (1.5) K/U T/I A
    (a) Imagine a familiar species' characteristics to be more like those of the dinosaurs.
    (b) Using these new characteristics as evidence, explain why your imaginary species might be the descendant of the dinosaurs. Be creative.
85. Prokaryotes are extremely important organisms in many ways. Bacteria are the prokaryotic organisms we are most familiar with. They can be very harmful to us, but they can also play very positive roles. (2.1) K/U T/I A
    (a) Compare and contrast a harmful prokaryotic bacteria with one that is known to be beneficial.
    (b) Which of the two do you think has the biggest impact on human life? Why?
86. Antibiotics are immensely valuable to humans. Explain how antibiotics work. What makes them so important? (2.1) T/I A
87. Compare and contrast bacteria and viruses. What about their characteristics makes them so different? What roles do they each play in the lives of humans? (2.2) T/I A
88. Explain how vaccines have helped in the fight against many of the world's most devastating diseases. (2.2) T/I A
89. The fact that there is no "typical" protist is curious, in light of the similarities in each of the other five kingdoms. (2.3) K/U T/I
    (a) Break down some of the differences that exist among the protists.
    (b) Hypothesize as to why there is this wide variance in the Protist Kingdom.
90. Fungi are some of the most common but least visible organisms on Earth. (3.1) K/U T/I A
    (a) Analyze the characteristics of fungi.
    (b) Use your analysis to assess why these organisms are relatively unfamiliar to many people.
91. Some fungi have fascinating symbiotic relationships with animals. (3.1) K/U T/I
    (a) Explain what it means to have a symbiotic relationship with another organism.
    (b) Examine and report on a symbiotic relationship between a fungus and another organism or species.
    (c) Compare the symbiotic relationship you discussed above with one that you have as a human with another species.
92. Plants dominate most of the land on Earth. They can survive in many different climatic conditions, from hot and humid tropics to parched deserts and the extreme cold of the High Arctic. Because plants are producers of food, wherever they live, other terrestrial life forms follow. (3.2) K/U T/I A
    (a) Examine and compare two different plants that each thrive in very different, though extreme, climates. What makes each of these plants suitable for the extreme environment in which it lives?
    (b) Name another species that also calls each of these extreme habitats home because it depends on the plants described above.
93. Most plant species alive today live on land. There are some aquatic species, but most are freshwater—only a few are marine. Hypothesize as to why this is so. (3.2) K/U T/I
94. Illustrate the advantages seed plants have over non-seeding plants. In what ecosystems, climates, and weather can only a seed plant thrive? Why is this so? (3.2) T/I A
95. We depend on many other animal species for our survival. We use many species of wild and domesticated animals as sources of food and other products. Our dependency, however, goes far beyond sources of food. (3.3) K/U T/I A
    (a) Investigate two uses for which humans depend on other animals that does not involve eating them.
    (b) What makes these uses so important to us? Are there other ways to have the same needs met? If not, why? If so, what might they be?

96. The common ancestor of all animals was likely a colonial, flagellated protist that lived at least 700 million years ago. Since that early organism, countless other organisms have been the common ancestors of more closely grouped species of animals. (3.3) T/I A
    (a) Choose three different species of animals with which you are familiar. Describe each one's characteristics.
    (b) Based on the three sets of characteristics, hypothesize what the common ancestor of all three organisms might look like and act like. What characteristics might it have?
97. Although greatly outnumbered by the invertebrates, the vertebrates are nonetheless a diverse and dominant group of animals. Vertebrates have the most advanced organ systems and most complex behaviours of all organisms. These features enable many vertebrates to inhabit environments that other organisms cannot. (3.3) K/U T/I
    (a) Research and report on two examples of vertebrates that inhabit, or at least can survive in, extreme conditions.
    (b) Analyze why each vertebrate is well suited to its habitat. What about these vertebrates makes them adaptable to extreme conditions?

Evaluation

98. There is no doubt that all species depend on one another. Maintaining and enhancing biodiversity is essential for the health and sustainability of ecosystems. (1.1) T/I C A
    (a) Visit a local ecosystem or a habitat that you know is at risk today. Walk around and study its diversity of life. Take notes on what you observe.
    (b) Construct a detailed report on your findings that includes recommendations to slow, correct, or rectify the decline that this ecosystem or habitat is experiencing.
    (c) Communicate your plan in a pamphlet that you could present to your local wildlife commission.
99. Classifying organisms into various taxa with defined criteria provides a framework for identifying organisms. Today, most biologists and taxonomists consider all organisms to fall under one of six kingdoms: Plants, Animals, Fungi, Protista, Archaea, and Eubacteria. (1.2, 1.4) K/U T/I A
    (a) Make an argument for plants and animals to be grouped in the same kingdom, using morphological characteristics.
    (b) Also consider different evidence for your argument that is not based on morphological characteristics. Be creative.
100. Phylogeny is the science that deals with evolutionary relationships between and among species—entire populations of individuals. In many ways, these relationships, or kinships, are similar to a large family tree. (1.3) K/U T/I A
    (a) Based on what you have learned about phylogeny and phylogenetic trees, design a family tree that shows your extended family, going back several generations.
    (b) How is this tree and how are the relationships within your family similar to the phylogenetic trees you learned about in Chapter 1?
101. The Linnaean classification system recognized only two kingdoms of living things—Animals and Plants. When biologists began to use microscopes, they discovered many new micro-organisms and gained a better understanding of the cellular structure of living things. It is conceivable, then, that the modern classification system will change based on new discoveries and knowledge. Based on what you have learned, invent a seventh kingdom of life. Be sure the organisms in your kingdom are unique. Describe them in detail. Be creative. (1.4) T/I A
102. Fossil evidence links birds closely with a group of carnivorous dinosaurs. Morphological and genetic evidence also suggests that birds' closest living relatives are the crocodiles. Based on what you have learned about classifying organisms using both fossil evidence and physical characteristics, invent an adapted bird group that more closely aligns with either the mammalia or amphibia taxon. Be sure to include detailed characteristics in your description of this "new" bird to support your decision to add these creatures to their new class. Be creative. (1.5) K/U T/I A
103. Viruses are small, non-living particles. They cannot grow or reproduce on their own. They do not produce or use energy, nor do they create waste. Viruses enter into and take over control of healthy cells. The cell eventually makes copies of the virus. Consider what a different type of virus might be capable of—a virus that was a living thing that needed no host cell to infect, contaminate, or damage. (2.2) K/U T/I A
    (a) Describe the characteristics of this living virus.
    (b) Predict what would be different about our world with these types of viruses around.

104. Assume the role of an adventure tour guide. Your most important responsibility is to keep your tourists safe and healthy during their time with you. Formulate a plan to make all drinking water collected during your adventure safe for drinking. Communicate your plan in the form of a pamphlet to pass out to each tourist at the onset of your adventure. Be sure to discuss the potential dangers and diseases that could result from not purifying all drinking water. (2.3) K/U T/I A

105. Consider the statement "fungi are the major decomposers on Earth." Think about what this means. Are they more harmful or more beneficial to us and to their surrounding environment? What would be different about the world without them and their ability to decompose? Choose an ecosystem where they are prevalent and modify it by removing all forms of fungi. Predict how their absence would change things. (3.1) T/I C

106. Although we are surrounded and supported by ecosystems dominated by plants, most people know very little about them and may think there is not much to know. There is, however, a great deal to know about these very important organisms. (3.2) T/I C A
    (a) Create a short lesson plan in which you engage the interest of your classmates to discover more about plants.
    (b) Include in your lesson those things you find interesting, fascinating, and important about plants. What makes them so interesting and so important? Why are they essential to our lives?

107. Compare and contrast the simplest invertebrates with the most complex vertebrates. How are these species different? What are their similarities? Make an argument for these two very different organisms to be classified into separate kingdoms. (3.3) K/U T/I C A

Reflect on Your Learning

108. Assume the role of taxonomist for your local region. In this new position, you are asked to describe and classify many of the animals and plants native to your area. Using methods learned in your reading of this unit, create a report and classification system that covers as many of the animal and plant species in your region as possible. T/I C A

109. Visit your public or school library or a local bookstore. Take careful notes on how the books are sorted and displayed using a sorting and classification system. Back at your home, create an elaborate table modelled after the traditional taxonomic ranks of classification. Be sure to include as many types and genres of books as you can. T/I C A

110. The development of vaccines was one of the greatest achievements in medicine. Based on what you learned about bacteria, viruses, diseases, and vaccines, imagine a world in which vaccines did not exist. Describe this world in detail, including the short-term and long-term effects on humans. How would it be different? T/I C A

111. Present a strong argument in favour of placing humans in their own taxon. Include information on how your position on classifying humans makes more sense for taxonomists. In your argument, use detailed information from the unit. Make your argument convincing to others. T/I C A

112. Plants are thought to have evolved from charophytes, a group of green oceanic algae. Most plant species living today, though, live on land. What if plants returned to the sea? Write a report on the worldwide consequences that would ensue if all land plants returned to the sea. What would life on Earth be like without land plants? How would it affect humans and animals? Would our continued existence be possible? Support your answer with facts from Unit 1. T/I C A

Research

GO TO NELSON SCIENCE

113. Research a species of animal on the Internet that you know exists only in Canada. In your research, identify how the specific Canadian ecosystem and environment in which this species has existed has resulted in its lack of presence elsewhere in the world. What other factors played roles in how the species has depended on this location? Write a report on your findings. Present your report to your classmates. T/I C A

114. Scientists have studied dinosaurs for many years, but there is much we do not know about them. Choose three different species of dinosaur and gather information about them. Based on what you learn, classify them in a phylogenetic tree. T/I

115. Type the name Louis Pasteur into a search engine. Gather as much information as you can on this important scientist, including all of his contributions to medicine and microbiology. Write a report on your findings. Present your report to your classmates. T/I C

116. The classification system developed by Carl Linnaeus (**Figure 2**) in the eighteenth century is very different from the phylogenetic classification system many scientists use today. Research how systems of biological classifications have changed as new scientific discoveries are made. How might these changes affect our understanding of biodiversity? T/I A

Figure 2 Carl Linnaeus

117. Tuberculosis is a bacterial lung disease caused by *Mycobacterium tuberculosis*. It is responsible for the deaths of about 2 million people each year. It is often detected using X-rays (**Figure 3**). Research how this disease is spread, diagnosed, and treated. What factors affect how quickly the disease spreads? What measures can be taken to prevent the spread of the disease? T/I A

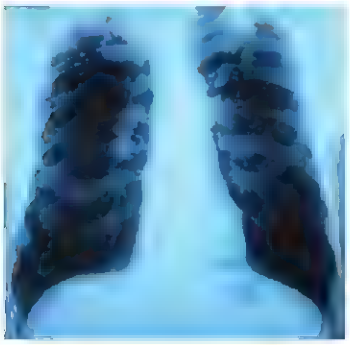


Figure 3 A tuberculosis infection is often detected using X-rays. It appears as cloudy white areas in the chest cavity.

118. Research one virus of your choosing on the Internet. Discover as much as you can about its characteristics, symptoms, and treatments. Write a report on your findings. Include in your report any recommendations you might have for how this disease can be controlled. Present your report to your classmates. T/I C A

119. Slime moulds are now classified as protists, but they were once considered to be a type of fungus. One type of slime mould, *Physarum polycephalum*, astounded scientists recently because of its ability to build effective networks. Research this organism and summarize how scientists are using it to study network construction. T/I

120. Research flowering plants on the Internet. As more than 90 % of all modern plants are angiosperms, or flowering plants, they are obviously the most prominent and important type of plant. Study and report on what makes them different from non-flowering plants. What characteristics give them such an enormous edge, compared with the proportion of gymnosperms? Present your report to your classmates. T/I C A

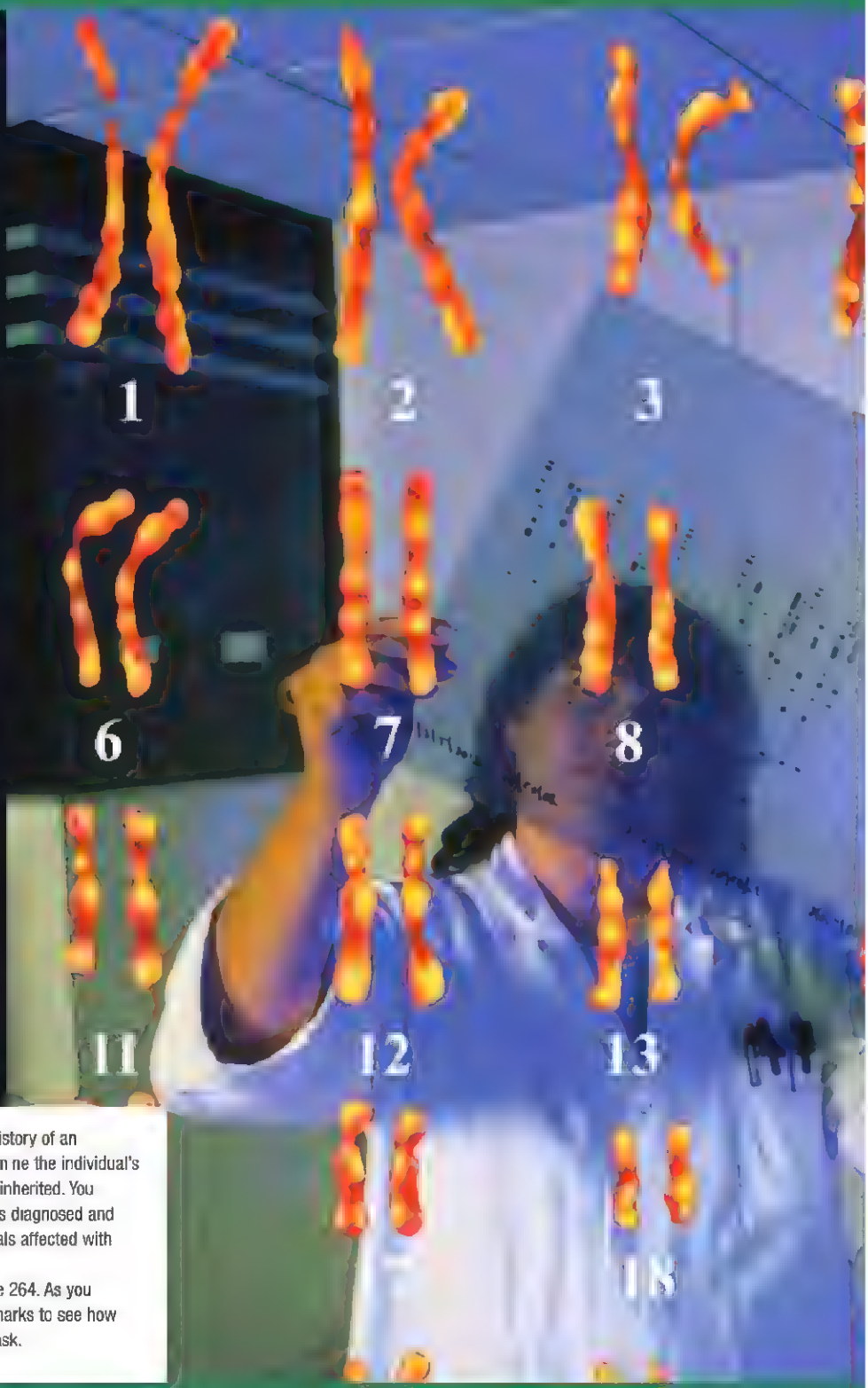
121. Research the concept and role of today's fisheries. Investigate what, exactly, these important commercial enterprises do. Why do many scientists believe that more than half of all major fisheries are unsustainable and in decline? K/U T/I

122. Many of our most useful inventions were inspired by nature. For example, George de Maestral invented Velcro after studying how burrs stuck to his dog's fur. This is an example of biomimicry—human-made inventions that mimic what is found in nature. Research another example of biomimicry. What inspired it? How is it used? T/I A

123. The largest living thing is not a blue whale or a giant redwood tree—it is a fungus. Single individuals of the genus *Armillaria* are known to spread out beneath the ground over areas of thousands of hectares. The largest has a mass of at least 150 tonnes and is thought to be more than 2400 years old! These fungi also cause disease in trees. Research these fungi. How do they affect the forestry industry? How might they be affected by climate change? T/I A

UNIT 2

Genetic Processes



OVERALL EXPECTATIONS

- evaluate the importance of recent contributions to our knowledge of genetic processes, and analyze the social and ethical implications of genetic and genomic research
- investigate genetic processes, including those that occur during meiosis, and analyze data to solve basic genetics problems involving monohybrid and dihybrid crosses
- demonstrate an understanding of concepts, processes, and technologies related to the transmission of hereditary characteristics

BIG IDEAS

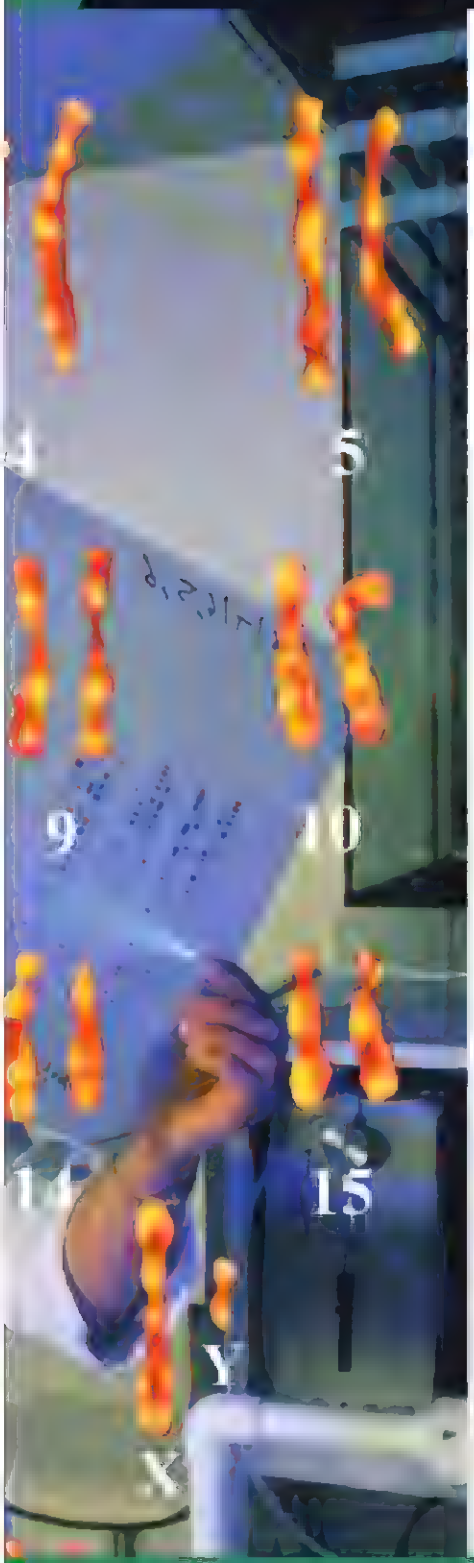
- Genetic and genomic research can have social and environmental implications.
- Variability and diversity of organisms result from the distribution of genetic materials during the process of meiosis.

UNIT TASK PREVIEW

In the Unit Task you will investigate the case history of an individual with a genetic disorder. You will examine the individual's family history and learn how the disorder was inherited. You will also learn about the disease itself, how it is diagnosed and treated, and what the prognosis is for individuals affected with the disorder.

The Unit Task is described in detail on page 264. As you work through the unit look for Unit Task Bookmarks to see how information in the section relates to the Unit Task.

FOCUS ON **STSE**



SHAPING OUR PAST AND OUR FUTURE

The science of genetics is revolutionizing biology. At the beginning of the last century, we were just beginning to understand the nature of inheritance. By the middle of that century, we had learned that chromosomes carry genetic information that is inherited from generation to generation. Later in the century, scientists were able to identify the structure of DNA. Today, we have the ability to read the genetic instructions of an individual, as well as the technology to transfer genetic information between individuals of different species. What are the applications and implications of these revolutions in genetics?

In hospitals, newborn babies are routinely screened for genetic disorders, enabling diagnosis, treatment, and reduced suffering. In courtrooms, DNA fingerprinting is used to distinguish between guilt and innocence. Organisms that have been genetically modified are used in agriculture to produce new foods, in forestry to yield faster-growing trees, and in the pharmaceutical industry to produce new and more effective drugs. DNA testing is now available to anyone, for a price.

The science of genetics and its applications have significant implications for society. Many of these applications offer the promise of improved healthcare, more abundant and nutritious food, and benefits for society and the environment. But what are the costs and risks of this revolution in science? Will the introduction of genetically modified organisms harm the environment? Will genetically modified organisms be used in a harmful way? How will genetic information be used, and will it be abused?

The future of genetics is filled with opportunities and burdened with difficult questions. Although many breakthroughs in genetics research have benefited society, many applications of genetics remain controversial. This unit will introduce you to the science of genetics and heredity. You will learn how the science of genetics and its associated technologies have shaped your world and will shape your future.

Questions

1. Make a list of six dog breeds. For each breed listed, identify which of its characteristics (physical and/or behavioural) are inherited (passed from generation to generation.)

2. (a) Brainstorm a list of eight human physical traits that are inherited but variable—for example, eye colour.
   (b) List some human behavioural traits that you think are inherited.

3. Many people are opposed to the use of organisms in agriculture that have been genetically modified. Why do you think this is? Why do you think others are so strongly in favour of their use?

4. If you could change any kind of organism, which kind would you choose, and what specific characteristic(s) would you change? Explain your answer.

UNIT 2 ARE YOU READY?

CONCEPTS

- identify cell structures and describe their functions
- use appropriate terminology related to cells
- explain the importance of cell division in growth and repair
- describe the phases of mitosis and cytokinesis
- recognize that errors of cell division have the potential to cause disease

SKILLS

- draw labelled biological drawings
- examine cells under a microscope
- communicate ideas, plans, procedures, results, and conclusions using appropriate language and formats
- analyze and interpret qualitative and/or quantitative data
- apply the mathematical concepts of ratio and proportion

Concepts Review

1. Match the cell structures on the left with the most appropriate descriptions on the right. K/U

(a) mitochondria	(i) site of photosynthesis
(b) nucleus	(ii) structure within the nucleus that contains genetic information
(c) cell membrane	(iii) point of attachment of spindle fibres during mitosis
(d) chloroplast	(iv) controls what enters and leaves the cell
(e) chromosome	(v) site of cellular respiration
(f) centromere	(vi) contains the cell's chromosomes

2. Identify the parts of the cell shown in **Figure 1.** K/U

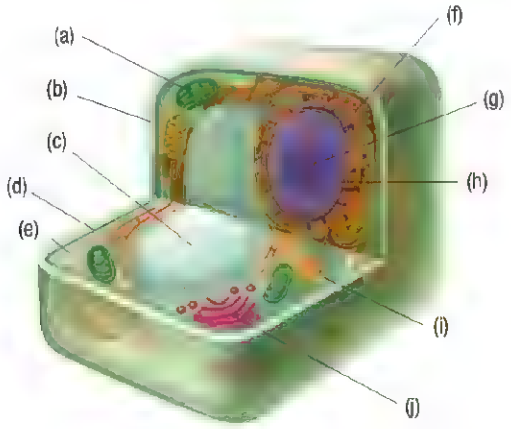


Figure 1

3. Growth and reproduction are related to the processes of mitosis and cytokinesis. K/U
   (a) Explain how mitosis and cytokinesis are required for growth.
   (b) Explain how mitosis and cytokinesis can be used for the purpose of reproduction.
   (c) Can all organisms reproduce using cell division? Explain.

4. Identify, and briefly explain, the function of each cell structure shown in **Figure 2.** K/U

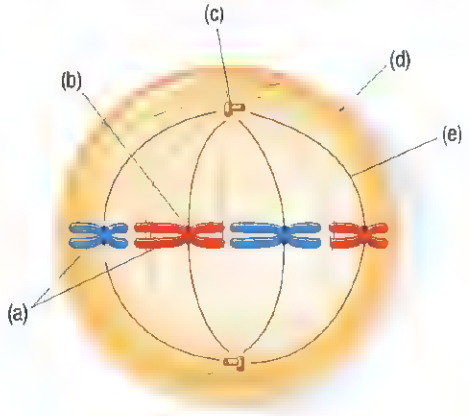


Figure 2

5. (a) **Figure 3** shows a Frayer diagram for the term *prokaryote*. Copy the diagram into your notebook and complete it.

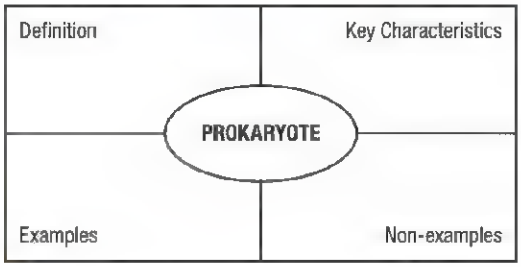


Figure 3

   (b) Draw and complete a new Frayer diagram for the term *eukaryote*. K/U T/I C

6. Explain the different ways in which mitosis and cytokinesis are useful for unicellular and multicellular organisms. K/U A

7. Interphase is sometimes called the "resting" stage of the cell cycle. Why is this a poor description of interphase? K/U

8. (a) Is mitosis occurring in your body right now?
   (b) What types of cells do you think are undergoing mitosis and cytokinesis? T/I A
9. What is meant by each of the following terms? K/U
   (a) cell differentiation
   (b) asexual reproduction
   (c) sex cells
10. A particular plant cell was found to contain 32 chromosomes during interphase. What would happen to the number of chromosomes in the cell if the plant cell underwent mitosis but then did not undergo cytokinesis? K/U T/I A
11. Describe the relationship between cancer and
    (a) cell division
    (b) mutations K/U
12. Define sexual and asexual reproduction, and provide examples of organisms that use these methods. K/U
13. A cat breeder mated a black male cat with a white female cat. All of the kittens were either white or black; none of them were grey. Does this surprise you? What does the colour of the offspring suggest about the inheritance of hair colour? K/U A
14. Scientists are attempting to genetically modify banana plants so that they produce vaccines within their fruits (**Figure 4**). Rather than receiving a needle injection, children could be vaccinated simply by eating one or more of these bananas. Do you think this is a good idea? Why or why not? A

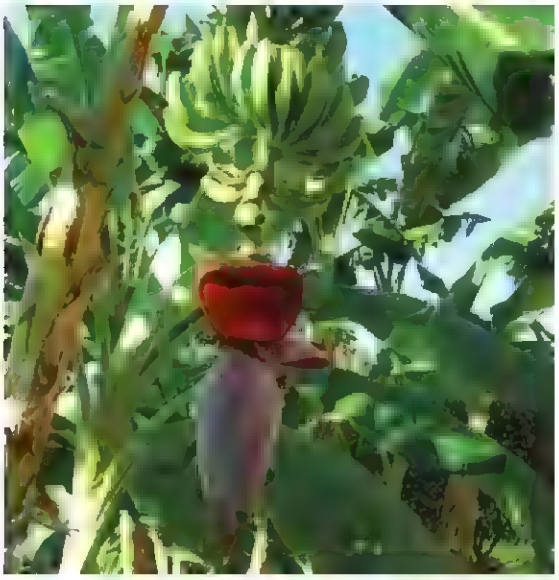


Figure 4 A banana plant

15. Identical twins are genetically identical to each other because they came from the same fertilized egg. K/U T/I A
    (a) Describe the physical characteristics they may share with each other.
    (b) Do you think the fact that they are genetically identical has any influence on how similar or dissimilar their personalities are?

Skills Review

16. Suppose you are planning to use the high-power objective lens. K/U
    (a) Describe the steps needed to focus when using the high-power objective lens.
    (b) What is the function of the diaphragm?
17. Describe the key things you must remember when making a proper biological drawing. K/U T/I A
18. Draw and label a simple diagram of the cell cycle. Include labels for interphase, mitosis, and cytokinesis. K/U A C
19. (a) What is the purpose of using a biological stain?
    (b) Describe how you would apply a stain to a specimen you wanted to view under the microscope. K/U T/I A
20. Biologists are often interested in comparing the ratio of one variable to another. After collecting data, they often convert ratios to simple whole number ratios. For example, wildlife biologists counted 20 lynx and 180 snowshoe hares in a large ecosystem. These values can be expressed as a ratio of 20:180 or 1:9. The expression 1:9 represents the lowest whole number ratio and means that for every 1 lynx there were 9 snowshoe hares.

    Calculate the lowest whole number ratios for the following samples: K/U T/I A
    (a) 2000 mice and 40 snakes
    (b) 48 maple trees and 16 pine trees
    (c) 181 native crayfish and 543 invasive rusty crayfish
    (d) 30 yellow roses, 90 red roses, and 60 pink roses

CAREER PATHWAYS PREVIEW

Throughout this unit you will see Career Links in the margins. These links mention careers that are relevant to the study of genetics. On the Chapter Summary page at the end of each chapter you will find a Career Pathways feature that shows you the educational requirements of the careers. There are also some career-related questions for you to research.

CHAPTER 4

Heredity and Reproduction

KEY CONCEPTS

After completing this chapter you will be able to

- describe how inherited characteristics are passed from generation to generation in the form of genetic information in chromosomes
- explain how asexual reproduction produces offspring that are genetically identical to the parent
- describe and explain how sexual reproduction results in genetic variation from generation to generation
- demonstrate an understanding of the processes and characteristics of asexual and sexual reproduction
- identify and discuss the many important applications of asexual and sexual reproduction, including those related to human health, agriculture, and the environment
- create biological drawings of cells undergoing meiosis
- construct and interpret chromosome arrangements (karyotypes)

What Is the Value of Variety?

No two people are exactly alike. Not even identical twins share the same set of facial features, hair colour, height, personality, and talents. Indeed, our uniqueness as individuals is one of our most valued qualities: it is what makes us special. This high degree of variation extends to most, if not all, other species. Virtually all species exhibit some degree of variation.

Variety is of great value. Breeders of dogs, cats, tropical fish, livestock, and other animals are very aware of the demand for variety. Consider the variety among dog breeds as an example. Chihuahuas, Labrador retrievers, and sled dogs all have very different characteristics. Chihuahuas are small and noisy house pets; retrievers have a built-in compulsion to fetch things; sled dogs have thick, warm coats, a desire to pull, and extraordinary endurance. Yet they are all dogs. Dog breeders are very aware of the demand for variety and will carefully mate selected individuals of the same breed to produce offspring that have specific characteristics desired by consumers. Similarly, cats, aquarium fish, and farm animals come in a dizzying array of shapes, sizes, colours, and temperaments.

Plant breeders face the same demands for variety. They breed fruits and vegetables with different qualities—flavour, size, hardiness, nutritional value, and disease resistance. Variation among ornamental plants is also in high demand. Horticulturists and home gardeners demand different colours, shapes, and sizes in the plants. They also need plants that are suited to their particular growing conditions. A type of rose that can flourish in Florida may not survive a winter in Ontario.

Amid all this diversity and variation there is also predictability and consistency. In fact, offspring often resemble their parents. Animal and plant breeders depend on this predictability to produce consistent varieties.

What is it about living things that enables them to exhibit tremendous variability, yet also causes them to bear such a strong resemblance to their parents? The answer lies in both the chemical nature of heritable information and the ways in which organisms reproduce.

In this chapter you will examine the role of asexual and sexual reproduction in passing on genetic information from one generation to the next. You will learn how these processes give rise to both the unity and the diversity of life. You will also explore some of the ways in which our understanding of inherited information can be used to benefit society and the environment.

STARTING POINTS

Answer the following questions using your current knowledge. You will have a chance to revisit these questions later, applying concepts and skills from the chapter.

1. How do you think genetic information gets passed on from generation to generation?
2. Do you think there are any biological advantages or disadvantages of asexual versus sexual reproduction?
3. How might an understanding of genetic processes and the inheritance of biological characteristics be of value to individuals and to society?

Mini Investigation

Variability—It's a Coin Toss!

Skills: Predicting, Performing, Observing, Analyzing, Evaluating

SKILLS HANDBOOK A2.1

As you know, individuals inherit biological information from their parents. How, then, is it possible that no two offspring will ever be the same—even when they have the same two parents? One key factor is chance. In this mini investigation, you will model the influence of random chance on the variability of a set of events.

Equipment and Materials: coin (any denomination)

1. Flip the coin and record whether the coin falls with "heads" or "tails" facing up. Do this eight times in total, each time recording your observations (for example, T, H, H, T, H, T, T, H).
2. Predict how many other students will have produced the same sequence by flipping their coin.
3. Your teacher will choose a student volunteer to read aloud the result of his or her *first* coin toss. Every student in the class with the *same* first toss must stand up—they are "a match." Next, the student volunteer will read aloud the result of his or her second coin toss. Students who were standing and have a match for the second toss are to remain standing. All other students are to be seated.
4. The student volunteer continues to read out his or her remaining six coin tosses. The other students remain standing only as long as they continue to match each and every toss. Record the number of students who matched all eight tosses.
5. Repeat Steps 3 and 4 with four different student volunteers to see how many students in the class have a match for their sequences of coin tosses.

A. How many students had a perfect match to one of the volunteers? T/I

B. Were you surprised at how few sequences matched? Explain why or why not. T/I A

C. Was there greater variability in an individual coin toss, or in the sequences of eight coin tosses? Explain. T/I A

D. The number of possible sequences is 2^n, where "n" is the number of tosses. How many different sequences of heads and tails are possible for eight coin tosses? T/I A

E. Calculate the number of possible sequences that could result from 23 coin tosses. T/I A

4.1 The Nature of Heredity

Cell division and reproduction are biological processes that are fundamental to life. All organisms use these processes to grow and reproduce. Multicellular organisms use cell division for growth and repair, whereas unicellular organisms use it as a means of reproduction. A key feature of cell division and reproduction is the passing of chromosomes from the parent cell to the daughter cells. Chromosomes carry information for traits (**Figure 1**). Thus, traits are passed from parents to offspring in a process known as **heredity**.

heredity the passing of traits from parents to offspring

Figure 1 Chromosomes as seen in an early stage of cell division

genetics the branch of biology dealing with heredity and the variation of inherited characteristics

deoxyribonucleic acid (DNA) a molecule that carries genetic information in cells

gene a segment of a DNA molecule that codes for a particular trait; found at a specific location on a chromosome

locus the location of a gene on a chromosome

Genetic Material

Genetics is the scientific study of heredity and variation. Living things inherit traits from their parents—but what causes traits to be passed on from parent to offspring?

Genetic material is a term used to describe all the material in an organism that stores genetic information. In a chromosome, genetic information is contained in a molecule of **deoxyribonucleic acid**, or **DNA**. As you will learn in Chapter 6, our understanding of the structure of DNA, and our ability to manipulate the genetic information it contains, has revolutionized the biological sciences. This knowledge has stemmed from the basic understanding of the organization of genetic material within cells and the mechanisms of heredity from one generation to the next.

Each DNA molecule is composed of hundreds of thousands of chemical subunits that act as a set of chemical instructions for the cell. These instructions occur as distinct sequences of information along the DNA molecule. Each of these distinct sequences of genetic information is called a gene. A **gene**, therefore, is a portion of a DNA molecule that carries the information that helps to produce a particular trait of an organism. Each gene occupies a specific location, or **locus** (plural—loci), on a chromosome (**Figure 2**). A typical chromosome carries information for hundreds or thousands of different genes.

When we "inherit" traits from our parents, what we actually inherit is genetic information. This genetic information is contained in segments of DNA called genes, and these genes are located at specific positions along chromosomes. Chromosomes, and all the genetic information they contain, are duplicated during cell division. You will learn more about how this information is passed on to offspring throughout the course of this unit.

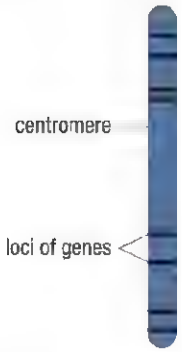


Figure 2 A typical human chromosome contains thousands of genes. Each gene is located at a different locus.

Chromosomes

Chromosomes are found in the nucleus of all eukaryotic cells, but vary widely between organisms of different species in their number, shape, and size. Some organisms have few chromosomes in their body cells, while others have many chromosomes in each body cell. Most multicellular organisms have less than 100 chromosomes in the nucleus of each body cell (**Table 1**).

In most multicellular organisms, chromosomes occur in sets. Diploid cells have two sets of chromosomes. Haploid cells have half the normal number of chromosomes. Some cells contain three or more sets of chromosomes and are referred to as **polyploids**.

Although much of the genetic material in a cell is composed of the DNA molecules in its nucleus, both mitochondria and chloroplasts contain small amounts of genetic material. You will learn more about the genetic material found in these organelles in Section 4.5.

Table 1 Chromosome Numbers in Assorted Species

Species	Number of chromosomes per body cell
human	46
dog	78
mosquito	6
banana	22

polyploid having more than two sets of chromosomes; many plants are polyploids

Reproduction: Copy or Combine?

Organisms inherit genetic information from their parents. Some organisms have only a single parent (asexual reproduction) while others have two parents (sexual reproduction). How do these different forms of reproduction influence heredity? What are the advantages and disadvantages of one form of reproduction over the other?

Asexual Reproduction

Asexual reproduction is a form of reproduction in which a new individual is produced from a single parent by cell division (that is, without the use of sex cells). While asexual reproduction can vary from species to species (**Figure 3**), it almost always involves cell division. As you may recall, cell division is a cellular process in which the chromosomes of the parent cell are duplicated and then divided such that each of two daughter cells receives one copy of each chromosome. The result is two new cells that are genetically identical to one another and to the parent cell. If one or more of these daughter cells develops into a new, independent individual, the result is asexual reproduction. The production of genetically identical offspring is a key distinguishing feature of asexual reproduction.

asexual reproduction the production of offspring from a single parent; the genetic makeup of the offspring is identical to that of the parent

There are several biological advantages to asexual reproduction. The parent organism does not have to seek out a mate, perform specialized mating behaviours, or possess specialized anatomy. In this way, nothing seems left to chance—asexual reproduction results in heredity that is direct and invariable. Generation after generation, offspring remain genetically identical to their parents.

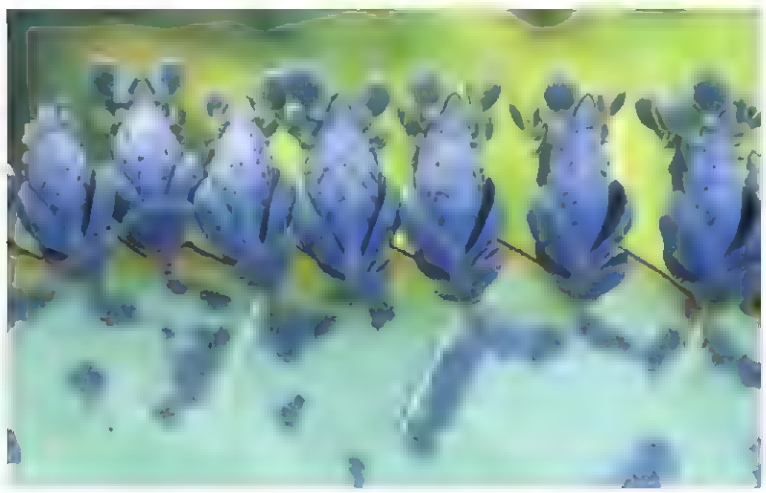


Figure 3 Known as the "mother of thousands" plant, *Kalanchoe daigremontiana* produces asexual "baby" plants along the edges of its leaves.

sexual reproduction the production of offspring from the fusion of two sex cells (usually from two different parents); the genetic makeup of the offspring is different from that of either parent

Sexual Reproduction

Sexual reproduction is a form of reproduction in which individuals are produced from the fusion of two sex cells. The sex cells usually, but not always, come from two different parent organisms. Offspring produced by sexual reproduction are not genetically identical to either of their parents and are rarely genetically identical to each other. Instead, they obtain half of their genetic information from each of their two parents. Sexual reproduction results in offspring that are genetically variable and contain equal amounts of genetic information from each of two parents.

There are a number of disadvantages to sexual reproduction. For example, animals and other organisms that reproduce sexually must have specialized organs to produce sex cells. In animals, producing mating calls or being brightly coloured can help attract a mate—but can also attract predators. In plants, producing flowers attracts pollinators like bees, but also requires the production of nectar. Sex is biologically "costly" and potentially risky (**Figure 4**). In addition, it is possible that the offspring may inherit a combination of genetic information that makes them weak and possibly unable to survive.

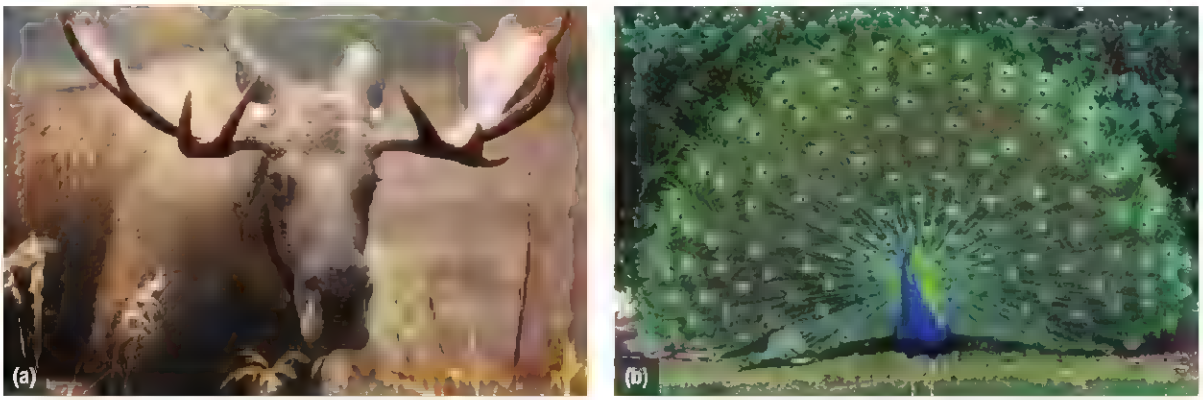


Figure 4 (a) An adult male moose grows a new and impressive set of antlers each year. Energy and nutrients are required for this process. (b) A peacock (a male peafowl) grows ornate tail feathers to attract peahens. This can be a disadvantage when it comes to avoiding predators.

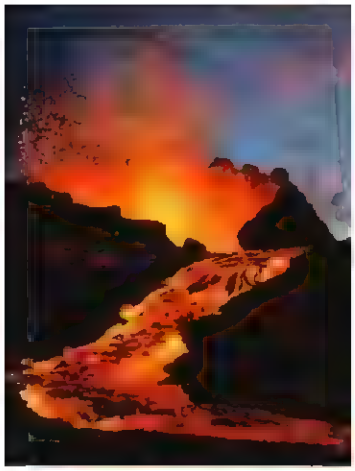


Figure 5 Volcanic eruptions can result in the destruction of previous ecosystems and the creation of new uninhabited ones

Why, then, do so many of Earth's organisms participate in some form of sexual reproduction? What is it about producing genetically variable offspring that creates a benefit worth the cost in time, energy, and resources?

The answer to these questions lies not solely with the individuals themselves but also with their surroundings. If individuals were to rely on asexual reproduction only, their descendants would remain almost genetically identical over countless generations. This might be beneficial if the original parent is well adapted to its environment and its environment is unchanging. However, this is rarely the case. Environments change, and these changes can be sudden: a fire, a volcanic eruption (**Figure 5**), or the introduction of a new disease or competitor. For example, if a new disease infects one individual, it could quickly infect virtually all individuals if they are genetically identical. This can be a significant problem in agriculture when plants are grown as monocultures—crops of a single species. Changes can also be slow and gradual: mountain formation, climate change, the evolution of a new species, or an old species slowly going extinct.

While asexual reproduction produces invariable offspring, this creates its own risk: if and when the environment changes, the individuals may no longer be well adapted. In contrast, sexual reproduction presents a different approach—the production of variable offspring, which may provide some insurance or flexibility into the future. Here, variability plays a prominent role; some offspring may not be well adapted for change, while others may be better adapted than their parents to a new environment. In the sections and units that follow, you will explore the relationships between reproduction, heredity, and the environment.

4.1 Summary

- A fundamental aspect of reproduction is the passing on of genetic information from one generation to the next.
- Genetic information is stored in DNA molecules within the chromosomes of cells.
- Portions of the DNA molecule, called genes, carry heritable information and are found at distinct locations on a chromosome.
- Chromosome number, shape, and size vary from species to species.
- Asexual reproduction results in offspring that are genetically identical to their single parent.
- Sexual reproduction results in offspring that are genetically variable. Offspring inherit half of their genetic information from each of two parents.

4.1 Questions

1. In your own words, describe the relationship between each of the following pairs of terms: K/U A
   (a) reproduction and heredity
   (b) DNA and chromosomes
   (c) genetic information and gene
   (d) diploid and haploid
2. Draw a labelled sketch of a single chromosome, identifying as many of the structures discussed in this section as possible. How many chromosomes are found in a single human body cell? K/U C
3. (a) Use the Internet to research and compare the diploid numbers of the following pairs of species: K/U T/I ICT A
   (i) lion and tiger
   (ii) elephant and woolly mammoth
   (iii) chimpanzee and gorilla
   (iv) dog and wolf
   (v) wolf and red fox
   (b) What do you notice about chromosome number and the similarity of these species?
   (c) Choose any two other "pairs" of animals and compare their chromosome numbers. Comment on your findings.
4. Use a Venn diagram or chart to compare heredity in asexual and sexual reproduction. K/U C
5. List several biological advantages of asexual reproduction. Explain your reasoning. K/U A
6. Describe the added "costs" of sexual reproduction for an organism. K/U
7. When is the production of genetically identical offspring a disadvantage? Explain your reasoning. K/U A
8. (a) Brainstorm several examples of environmental changes not mentioned in the text that are
   (i) sudden and rapid
   (ii) slow and gradual
   (b) For each change, consider how the change might differently impact species that are reproducing sexually compared to those that are reproducing asexually. T/I A
9. Moose antlers and peacock tails are classic examples of features related to sexual reproduction. Explain what advantages and disadvantages might be associated with each of the following: A
   (a) mating calls of birds
   (b) release of chemical scents into the air by female moths
   (c) the very large size of male elephant seals compared to females
   (d) the production of nectar by many flowers
10. Look at the butterfly in **Figure 6**. It has inherited an interesting set of markings on its body and wings. K/U T/I A
    (a) How might such an inherited feature benefit the butterfly?
    (b) Do you think it is possible for this inherited feature to help the butterfly reproduce? Why or why not?

Figure 6

GO TO NELSON SCIENCE

4.2 Asexual Reproduction: Copies and Clones

Asexual reproduction is common in nature. Many organisms reproduce asexually for at least part of their life cycle. Asexual reproduction is the most common form of reproduction among unicellular organisms and is also widespread among many multicellular groups—particularly plants and fungi. Many aquatic and terrestrial invertebrates undergo asexual reproduction, but it is rare among vertebrates.

Modes of Asexual Reproduction

Asexual reproduction can be both advantageous and practical. Recall from Grade 10 that many plants produce asexually by putting out roots or shoots that develop into new plants. Imagine that a small plant seed—from a strawberry, for example—is blown or carried onto a large patch of bare ground. The seed germinates and begins to grow, and the plant is soon ready to reproduce. Instead of producing flowers, it starts sending out runners (**Figure 1(a)**). These above-ground stems, produced by cell division, quickly extend and develop into new plants. These new young plants in turn grow and begin sending out their own runners. In a relatively short time, many new individual plants quickly spread out and occupy their new environment—a biological success story!

Budding is one type of asexual reproduction in which a new individual develops from an outgrowth on the body of an organism. The hydra, a simple multicellular animal related to the jellyfish, can reproduce asexually by budding (**Figure 1(b)**). When growing conditions are favourable, hydra grow one or more extensions on the sides of their bodies. When they are sufficiently large, these "buds" detach and begin living freely as new, genetically identical individuals.

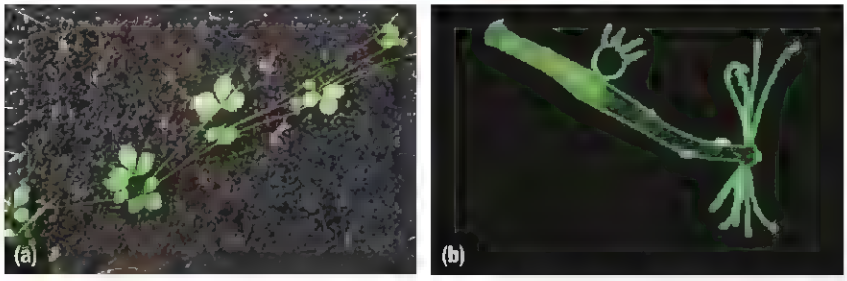


Figure 1 Many plants, (a) such as this strawberry, and animals, (b) such as the hydra, are capable of asexual reproduction, producing offspring from the direct outgrowth of their body.

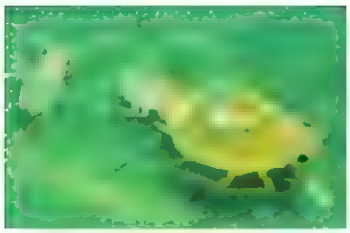


Figure 2 Female aphids can reproduce asexually, giving live birth to genetically identical female offspring

Not all asexual reproduction involves the direct outward growth of new individuals from the body of the parent. A fascinating and dramatic example is that of aphids—a group of more than 4000 species of small insects that feed on plants. Female aphids give birth to female offspring (**Figure 2**). These new females are able to start giving birth to more females when they are only a few days old. Since all the new individuals are females, the number of aphids can skyrocket over the course of a few weeks. One species was documented as having produced 41 generations of offspring in a single year!

These numbers are staggering. Beginning in the spring, a female of this species and her descendants are capable of producing a population of over a trillion individuals by late fall. In aphids and many other species, hormonal changes that occur in autumn cause the females to begin giving birth to males as well as females. These aphids then reproduce sexually—providing an opportunity for genetic diversity.

All species of fungi are thought to be capable of asexual reproduction. In fungi, asexual reproduction usually results from **fragmentation**—a process in which parts of the growing mass of fungi simply break off and continue to grow independently.

While the frequency and patterns of asexual reproduction are highly variable from species to species, at the cellular level, they usually share one key process—mitosis.

fragmentation a method of asexual reproduction in which a piece or body fragment of the parent organism develops into a mature individual

Cell Division

As you may recall from Grade 10, cell division consists of mitosis and cytokinesis—two of the stages of the cell cycle. **Mitosis** is the stage of the cell cycle during which the genetic material in the nucleus of a eukaryotic cell is divided equally into two new nuclei. The rest of the cell divides during cytokinesis. Some scientists use the term "mitosis" to include both nuclear division and cytokinesis.

mitosis the process by which a eukaryotic cell divides the genetic material in its nucleus into two new identical nuclei

The third stage of the cell cycle, during which cells are between cell divisions, is called **interphase**. During interphase, the cell grows and carries out its normal functions. The chromosomes in the nucleus form a mass of thread-like structures called **chromatin**, which are composed of DNA and proteins. When in the form of chromatin, the chromosomes are long, thin strands dispersed throughout the nucleus.

interphase the portion of the cell cycle between mitotic divisions when the genetic material (in the form of chromatin) is duplicated

chromatin the tangled strands of DNA and protein within a eukaryotic nucleus

The replication of chromosomes during interphase results in pairs of sister chromatids, each containing exactly the same genes at the same loci. Each original chromosome and its duplicate remain attached by a structure called the centromere. While attached, they are referred to as **sister chromatids**. In Section 4.1, you read that each chromosome contains large numbers of genes at specific loci. During the time that sister chromatids remain attached to each other, they are considered to be one chromosome (**Figure 3**).

sister chromatid the identical copy of a single chromosome that remains attached to the original chromosome at the centromere

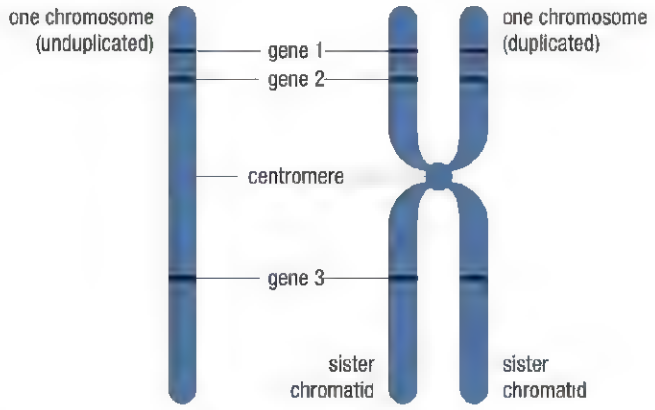


Figure 3 A doubled chromosome is composed of two identical sister chromatids held together at the centromere. Each sister chromatid contains exact copies of the same genes.

LEARNING TIP

Chromosome Composition
An unduplicated chromosome is made up of a single DNA molecule and its associated proteins.

As you review the phases of mitosis, you may notice that all chromosomes behave in the same way, with every cell getting a copy of every chromosome. As you will soon learn, this is not true during sex cell formation, when chromosomes are arranged in pairs and sorted accordingly.

Almost all of the heritable information in a cell is carried on chromosomes contained in the nucleus. Sister chromatids carry identical copies of this information, so cells receiving identical sister chromatids also receive identical genetic information. In rare cases, if cells do not receive identical copies of sister chromatids, then they will not receive the same information and will differ genetically from each other.

Prophase

Prophase is the first phase of mitosis (**Figure 4**). During prophase I the chromosomes begin to shorten and thicken and become visible under a microscope. In animal cells, small protein bodies in the cytoplasm called centrioles separate and move to opposite poles of the cell. Centrioles are involved in the formation and organization of spindle fibres, which attach to the chromosomes during cell division. The centromere helps anchor the chromosomes to the spindle fibres. Most plant and fungi cells lack centrioles but still produce a similar set of spindle fibres.

During prophase, the nuclear membrane starts to dissolve. This will eventually allow the chromosomes to separate into the two new daughter cells.

Metaphase

The second phase of mitosis is metaphase. During metaphase, the spindle fibres begin moving and aligning the chromosomes. Each chromosome, composed of sister chromatids, is pulled toward the centre of the cell, where its centromere becomes aligned across the middle, or equator, of the cell.

Anaphase

The third phase of mitosis is anaphase. The centromeres divide, and the sister chromatids, now referred to as chromosomes, move to opposite poles of the cell. The chromosomes are being pulled by their centromeres, resulting in a distinctive pattern with the ends of the chromosomes trailing behind. If mitosis proceeds correctly, the same number and type of chromosomes will be found at each pole of the cell.

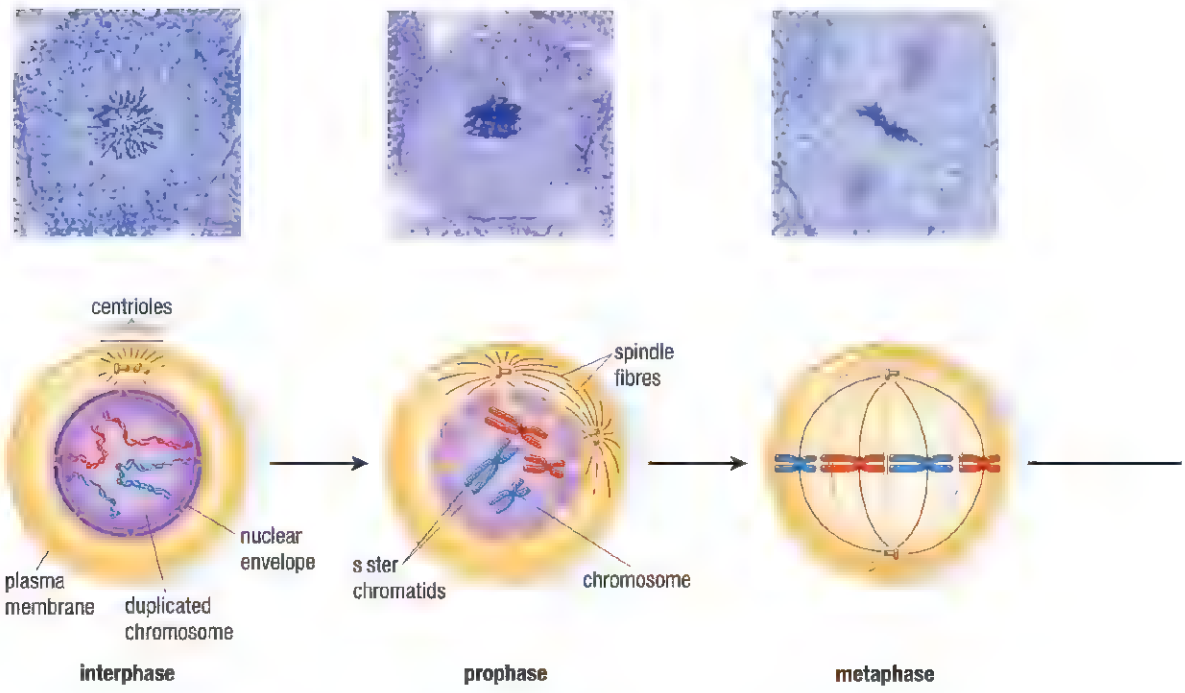


Figure 4 Mitotic cell division in an animal cell (diagram continues onto next page)

Telophase

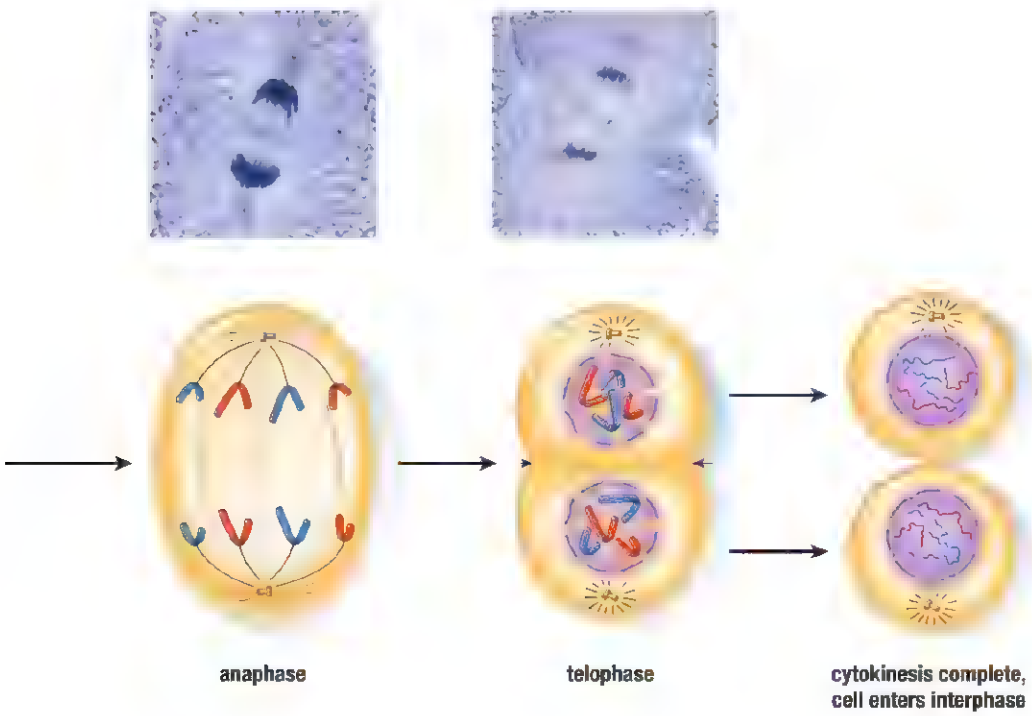
The last phase of mitosis is telophase. Here, chromosomes reach the opposite poles of the cell and begin to unwind. As they do so, the spindle fibres dissolve and nuclear membranes form around the chromosomes. The result is two daughter nuclei.

Cytokinesis

Mitosis is followed immediately by **cytokinesis**, the stage of the cell cycle when the cytoplasm of a eukaryotic cell is divided to form two new cells. Although the nucleus is divided during mitosis, the division of the cell content into two new daughter cells occurs during cytokinesis. Hence, cell division occurs in two stages—mitosis and cytokinesis.

cytokinesis the process in which a eukaryotic cell divides its cytoplasm into two new daughter cells

In many protists, fungi, and animal cells, a furrow develops, pinching off the cell into two parts. In plant cells, vesicles produced by Golgi apparatus begin to gather on both sides of the cell equator. These vesicles then fuse, and their contents begin to form a cell plate between the daughter nuclei. The cell plate becomes the cell walls of the two new daughter cells, while the membranes of the Golgi vesicles unite to form new cell membranes. In both plant and animal cell cytokinesis, separation occurs at the midpoint along the original spindle fibres. In addition to separating the two new nuclei, cytokinesis separates the other organelles approximately equally. During the growth stage of the cell cycle, additional copies of organelles are formed.



Cloning—Does It Pay to Copy?

cloning the process of producing one individual that is genetically identical to another, using a single cell or tissue

biotechnology the use and modification of organisms for applications in engineering, industry, and medicine

In nature, many organisms reproduce asexually by mitotic cell division. The offspring, which are genetically identical to the parent, are referred to as clones. **Cloning** is the process of forming identical offspring from a single cell or tissue. Individuals produced by mitotic cell division are natural clones. However, cloning is not limited to natural processes. **Biotechnology** is a field of biology that involves the use of living things in engineering, industry, and medicine. Biotechnology includes cloning plants for use in agriculture. For example, plants with predictable traits could be cloned to produce larger crop yields. Biotechnology has many applications that are used to benefit society, but it also has potentially negative implications.

Plant Cloning

In 1958, plant biologist Frederick Steward announced his success in cloning a plant from a single carrot cell (**Figure 5**). The event was remarkable because Steward was able to clone a carrot plant beginning with mature, specialized cells from another carrot. By growing individual root cells in a nutrient-rich medium containing some plant hormones, Steward was able to get the cells to return to an undifferentiated state (lacking any resemblance to carrot tissues). The cells then restarted the process of growth, specialization, and development into new plants.

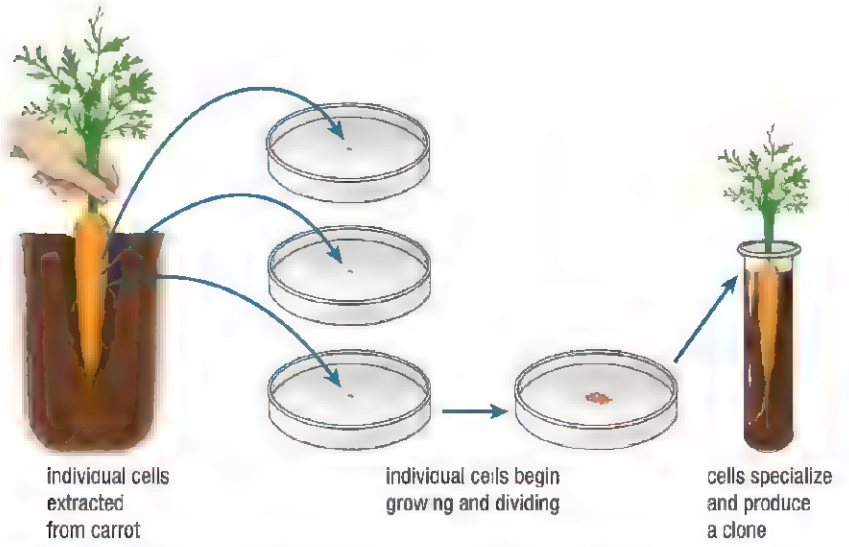


Figure 5 Plant cloning from a single cell enables growers to produce very large numbers of new plants from a single individual.

Today, this technique is commonly used to produce strains of plants with identical characteristics. Plant tissue cloning techniques are now widely used commercially. Valuable ornamental plants such as orchids and petunias can be cloned, as well as some valuable agricultural plants, including bananas and grapes. Other plant families, including important grasses and legumes, do not respond well to the same efforts and have proven difficult to clone.

The genetic control over asexual reproduction is an area of active research in plant biology. Some plants, such as eastern gamagrass, have the unusual ability to reproduce asexually through their seeds. Seeds are normally produced by sexual reproduction and differ from their parent. Gamagrass seeds are produced by mitotic division and are genetically identical to the parent plant. Recently, scientists were able to transfer the genes that control this ability from gamagrass to corn plants. The result is a variety of corn plant that produces seeds that germinate and grow into identical clones of the parent plant.

CAREER LINK

Horticulturist

Horticulturists research and work in plant cultivation in order to improve the quality, nutritional value, aesthetic value, and resistance to outside influences of plants. To learn more about being a horticulturist,

GO TO NELSON SCIENCE

Animal Cloning

On July 5, 1996, the world's most famous sheep, Dolly, was born. Dolly was the first mammal cloned from an adult body cell. The challenge to overcome was that animal body cells could not be stimulated into restarting the process of growth and differentiation that begins with a fertilized egg cell.

Dr. Ian Wilmut of the Roslin Institute in Scotland used a clever technique to get around this obstacle. He knew that he might not need to rely entirely on the adult cell to produce a genetic clone. The adult cell contained all the genetic information he wanted in its nucleus, but it did not have the special characteristics of an egg cell that lead to growth and differentiation.

His technique involved two cells and three adult sheep. He obtained a body cell from the adult sheep he wished to clone and an unfertilized egg cell from a second donor sheep. Then, using microscopic surgery techniques, he was able to enucleate, or remove, the nucleus from the egg cell (**Figure 6**). Wilmut then used an electrical shock to fuse the adult body cell with the enucleated egg cell. The result was an egg cell containing the nucleus (and complete set of chromosomes) from the adult body cell of a different sheep. Once this was done, Wilmut triggered the egg cell to begin dividing and growing into an embryo. The embryo was then implanted into the uterus of a third sheep, and, five months later, Dolly was born (**Figure 7**).

The research program that resulted in the birth of Dolly was an extremely difficult and challenging one. Dolly was the only successful clone out of 277 attempts. In the last decade, success rates have increased and many more species of mammals have been cloned from adults, including goats, cows, mice, pigs, dogs, cats, rabbits, horses, and camels. There are still many problems that develop in cloned organisms. Cloned individuals typically do not live as long as normal individuals and often suffer from a variety of health complications. Dolly died prematurely of a lung disease more common in older sheep. While it is not certain that her early death was related to her being cloned, she did exhibit additional signs of premature aging, including arthritis.

LEARNING TIP

Differentiation Dead End

An unfertilized egg cell grows and differentiates into a specialized cell with a specific function. Once the cell has differentiated, it loses its ability to change into a different kind of cell.

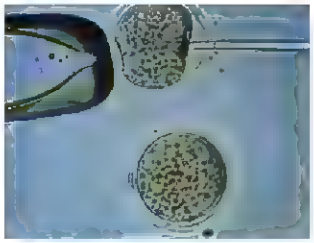


Figure 6 Microsurgical techniques can be used to remove the nucleus from a cell.

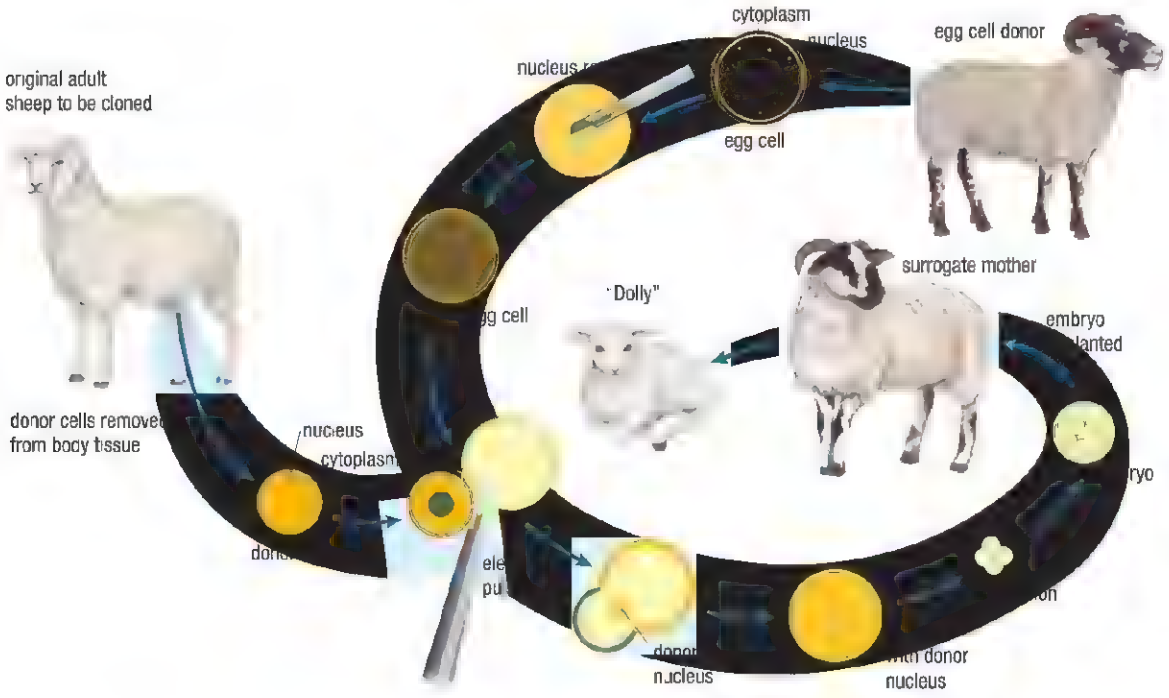


Figure 7 In 1996, Dolly was the first mammal to be cloned from an adult body cell. The process involved transferring an adult cell's nucleus into an egg cell in place of the original nucleus.

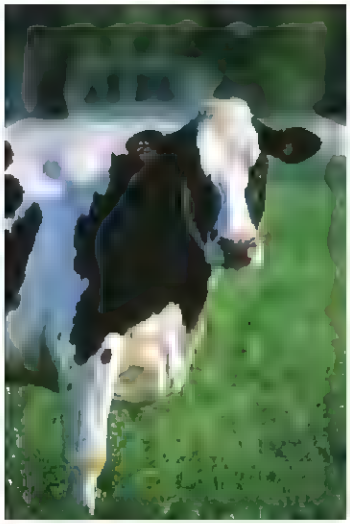


Figure 8 Prize Holstein cows can produce in excess of 75 L of milk per day. The average for the breed is closer to 30 L per day.

Applications and Implications of Cloning

You might be wondering what all the fuss is about. Why spend millions of dollars developing cloning technologies? The potential benefits of cloning are numerous and the implications are dramatic.

MASS PRODUCTION OF LIVESTOCK AND CROP PLANTS

The potential benefits of cloning are most evident in agriculture and horticulture, where prize animals and plants can be cloned on a massive scale to improve the production and quality of livestock and crop plants. By choosing parent organisms that are of the highest quality, farmers and growers can produce clones that will potentially increase yields. Thus, a dairy farmer with a herd of top-producing milking cows might have a significant advantage over a farmer with a herd of less productive cows (**Figure 8**). In this way, the production of genetically identical clones has the potential to yield significant benefits.

Innovations rarely come without costs and risks. Cloned plants and livestock may be very expensive for farmers to produce and maintain. Also, some consumers may avoid purchasing food from cloned organisms, feeling that it is unnatural or unethical. An additional concern is that although clones will all have the same inherited characteristics, some will be detrimental—for example, the same vulnerability to diseases. In this way, genetic uniformity is responsible for the greatest risks and limitations associated with the widespread use of cloned organisms.

All of these potential benefits, costs, and risks extend to society as a whole. While the quality and quantity of food may increase, available variety and choice may be reduced. Also, the long term risks associated with reduced genetic diversity are unknown and may be substantial.

CLONING GENETICALLY MODIFIED ORGANISMS

genetically modified organism an organism in which the genetic material has been altered using genetic engineering techniques

New biotechnology tools have given scientists the ability to alter the genetic material in an organism, producing **genetically modified organisms** (GMOs). Genetically modified organisms often carry genes that originated in a different species. These GMOs exhibit some of the characteristics of the gene donor species and are unique organisms.

We already use many genetically modified organisms daily. For example, virtually all commercial insulin is produced by bacteria and yeast that have been genetically engineered to contain copies of the human gene that codes for insulin. The bacteria and yeast use the genetic instructions to make human insulin, which is then purified and made available to people suffering from diabetes (**Figure 9(a)**).

Scientists at the University of Calgary recently inserted the human insulin gene into a safflower plant (**Figure 9(b)**). This is the first time a plant has been genetically engineered to produce insulin, and it is very cost effective. It is estimated that a hectare of cloned plants could produce 2.5 kg of insulin—enough to treat 2500 insulin patients for an entire year! The entire world's supply of insulin could be produced on 65 square kilometres of prairie farmland.

CAREER **LINK**

Patent Attorney

There are many ways to combine a legal career with the biological sciences. For example, biotechnology patent attorneys work to protect and control biotechnology discoveries and inventions. To learn more about the legal profession as it relates to biology,

GO TO NELSON SCIENCE

Figure 9 (a) Humulin is identical to human insulin and is produced by genetically engineered micro-organisms. (b) Now researchers have genetically engineered safflowers to produce the same substance. They hope this will reduce the cost of this very valuable drug.

The technological challenges and costs of creating genetically modified plants and animals are extremely high, so it makes economic sense to attempt to clone these individuals once they have been created. A few potential and highly innovative applications of genetically modified organisms are listed in **Table 1**.

Table 1 The Use of Genetically Mod fied (GM) Organisms in Medicine and Industry

Organism	New gene action	Benefit
GM goats	gene from the golden orb spider can be used to produce silk protein	Goats produce spider silk protein in their milk, which is then purified and used to make high-strength "spider web" fibre.
GM bananas	genes for the production of a hepatitis vaccine	Bananas would contain a vaccine—making vacc nes read ly available in developing countries.
GM pigs	gene involved in the production of omega 3 fatty acids	Pigs produce bacon and other pork products containing "hea thy" fats.
GM potatoes	genes involved in starch production have been altered	Potatoes produce starch that is more suitab e for ndustrial applications such as the production of biodegradable "eco-plastics."

Despite the great medical and commercial potential for genetic engineering, many people have moral, ethical, and health concerns with the idea. They worry about the future possibility and impact on society of genetically modifying humans. You will have an opportunity to investigate and consider this important issue later on in the unit.

CLONING ENDANGERED SPECIES

Scientists are very concerned about the number of species that are endangered. Ontario alone has 86 species of plants and animals that are currently listed as endangered and 100 more that are at risk.

Captive breeding programs can be used to help save endangered species. Unfortunately, many species from Ontario and around the world are extremely difficult to breed in captivity. Cloning provides an alternative.

In 2003, a banteng (wild bovine) from Java was successfully cloned (**Figure 10**). The success of cloning this endangered species gave scientists hope that cloning might even be used to clone extinct species.

Figure 10 It was not until 2003 that scientists at Advanced Cell Technology announced they had successfully cloned a "normal" banteng—an endangered species

The primary obstacle to cloning extinct species is the need for DNA, which is usually not available. In early 2009, an extinct Spanish ibex (wild goat) was cloned using a tissue sample from an adult ibex that had been frozen. The genetic material from the donor was then transferred into the egg cell of a closely related species of goat. Although the ibex later died of lung defects, the experiment opened the door to cloning extinct species.

Unfortunately, even the successful cloning of an endangered species would not guarantee its long-term survival. Just as with other clones, the lack of genetic variability is problematic. Without genetic variability among individuals, populations and entire species are vulnerable to environmental changes and disease. If we do succeed in cloning endangered and extinct species, it may be necessary to clone as many genetically different individuals as we possibly can.

Even if cloning an extinct species were successful, it is important to note that cloning would remain a last resort. In addition, cloning endangered and extinct species is a controversial issue.

Research This

Pet Clones

Skills: Researching, Analyzing, Evaluating, Communicating, Defending a Decision

SKILLS HANDBOOK A2.1, A5.1

Many people are extremely fond of their pets—so much so that they are willing to spend almost any amount of money to "get them back" after they have died. Does cloning provide such an opportunity? Is it possible to clone your pet, and if so, at what cost? Will the clone really be the same as the pet it replaces?

In this activity, you will use the Internet to examine the history of pet cloning.

1. Research the short history of pet cloning, including famous pet clones such as *Carbon Copy the Cat*, *Missyplycity*, and *Lancelot Encore* (**Figure 11**).

Figure 11 In 2008, an American couple paid more than $150 000 to have their late pet dog Lancelot cloned. The puppy clone, named Lancelot Encore, was created by the South Korean biotechnology company, BioArts International.

2. Research the different kinds of pets that have been cloned.
3. Research the cost of having a pet cloned.
4. Share your findings with a partner. Discuss your feelings on this topic.

A. What methods were used to clone the pets listed in Step 1? K/U A

B. According to your research, what other types of pets have been cloned? T/I A

C. Are cloned pets as healthy as normal animals? List three examples from your research to support your answer. T/I

D. Would you agree with the concept of pet cloning if it were inexpensive—no more than the cost of purchasing a new dog or cat? Why or why not? T/I A

E. What was the public reaction to the news that pet cloning had taken place? T/I

F. Do you believe pet cloning is acceptable? Why or why not? K/U C/I

G. Should individuals have the right to choose whether or not to clone their pet, or should pet cloning be regulated by governments? Explain your reasoning. T/I A

GO TO NELSON SCIENCE

4.2 Summary

- Asexual reproduction results in offspring that are genetically identical to a single parent.
- Cell division produces two daughter cells that are genetically identical to each other and to the original parent cell.
- Clones have little or no genetic variability.
- Mammals have been cloned from adult cells, but only with limited success.
- Applications of biotechnology include the production of valuable pharmaceutical and commercial products, high-quality plants and livestock, and prize individual animals.
- Cloned plants and animals are more vulnerable to changes in the environment and new diseases than are populations that exhibit genetic variability.
- Cloning may prove valuable in the fight to protect endangered species.

4.2 Questions

1. How does asexual reproduction benefit organisms that invade new environments? K/U A
2. Describe the reproductive behaviour of aphids. Why might it be advantageous to only produce females asexually during the summer months but then to switch to producing both males and females and performing sexual reproduction in the fall? K/U T/I A
3. Describe the key events involving chromosomes that take place during the following portions of the cell cycle: K/U
   (a) interphase
   (b) prophase
   (c) metaphase
   (d) anaphase
   (e) telophase
4. Compare the genetic material of cells before and after cell division. K/U C
5. Distinguish between a chromosome and a sister chromatid. K/U
6. Why might it be advantageous to clone a prize animal rather than simply breeding it with other individuals? What might be the disadvantages? K/U A
7. Make a set of simple labelled sketches to outline the key steps involved in cloning Dolly the sheep. K/U C
8. How does the use of cloned prize plants and animals reduce the possibility of improving these same species? K/U A
9. How has the use of genetic engineering and cloning benefited people suffering from diabetes? K/U A
10. The couple that paid more than $150 000 to have their deceased pet dog Lancelot cloned already had eight other dogs. How does this news story make you feel? Do you think it is acceptable to spend that much money on cloning a pet? How does it compare to spending a similar amount of money on an exotic sports car? C A
11. There are many applications of cloning technology. List the applications that you think are most acceptable and those that are least acceptable. Explain your reasoning. T/I A
12. There is little doubt that it will soon be technologically possible to clone humans. Comment on the concept of cloning humans. What arguments do you think people will make in support of, and in opposition to, human cloning? C A
13. Canadian scientists have successfully inserted the human insulin gene into safflowers, which can now produce insulin at low cost. Go online to research the current status of this technology, and then answer questions (a) through (d). T/I C
    (a) Are safflowers being used for the commercial production of human insulin?
    (b) Who "owns" the rights to this genetically modified organism? Is this a private company or a public institution?
    (c) Are safflowers being considered for any other gene transfers? If so, describe them.
    (d) Who has funded this scientific research and technology?

GO TO NELSON SCIENCE

4.3 Sexual Reproduction: Adding Variety

gamete a sex cell; includes sperm cells in males and egg cells in females

fertilization the formation of a zygote by the joining together, or fusion, of two gametes

zygote a cell produced by the fusion of two gametes

In sharp contrast to asexual reproduction, sexual reproduction produces genetic variety. Whereas offspring produced by asexual reproduction are genetic clones of the parent, offspring produced by sexual reproduction inherit genetic information from two parents. Each parent contributes a copy of half of its genetic information. This process of combining genetic information from two individuals results in offspring that differ genetically from their parents and from each other.

Sexual reproduction involves two key processes. The first is the formation of haploid sex cells, or **gametes**, which contain genetic information from the parents. The second process is **fertilization**, which occurs when two sex cells join to produce a **zygote**—the first cell of a new individual.

Modes of Sexual Reproduction

ova female sex cells (egg cells)

The sex cells of different organisms vary considerably in size, shape, and mobility. Most species produce two different types of sex cells. In animals, the reproductive organs that produce sex cells are the testes (which produce sperm cells) and the ovaries (which produce egg cells, or **ova**) (**Figure 1**).

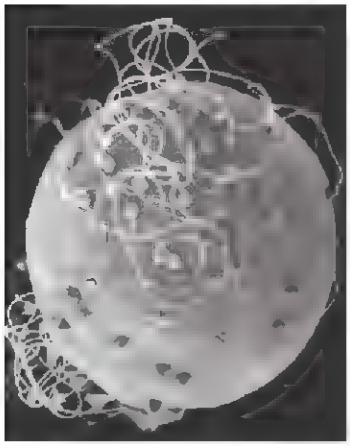


Figure 1 Sperm cells are able to swim using one or more flagella. Here many sperm can be seen surrounding the much larger egg cell, or ovum.

While simple plants like mosses and ferns also produce sperm, the male gametes of higher plants are contained within pollen grains. The sex cells of higher plants are produced in specialized sex organs called cones and flowers.

Many species have distinct male and female individuals—each possessing only one type of sex organ and the ability to produce only one kind of sex cell. Other species are hermaphroditic, meaning that they are composed of individuals that produce both male and female gametes. Fertilization strategies can be highly variable. **Table 1** highlights some of the diversity in sexual reproduction.

Table 1 Sexual Gametes and Fertilization Methods in Various Organisms

Organism	Types of individuals and gametes	Fertilization method
bread mould fungus	• "+" and "−" individuals produce similar-looking gametes where they come in contact	Gametes fuse, forming a zygote
willow tree	• Separate male and female trees • Male pollen grains and female eggs	Insects pollinate "pussy willow" flowers.
giant clam	• Young clams are males and change to females as they mature. • Sperm and egg cells	External fertilization. All individuals in an area simultaneously release their sex cells into the open water.
earthworm	• Hermaphrodites with both sperm and eggs	Internal fertilization. Two worms exchange sperm, fertilizing each other's eggs
parrot fish	• Separate males and females. • Fish can change sexes. • Sperm and egg cells	External fertilization. Sperm are released over eggs in water.
Canada goose	• Separate sexes • Sperm and egg cells	Internal fertilization

While types of individuals and methods of fertilization are highly variable across the kingdoms of life, the formation of gametes is less so. Most sexually reproducing eukaryotes produce specialized sex cells using a very similar process. In the remainder of this section, we will examine the formation of sex cells and the processes that influence and determine their genetic contents.

Meiosis

Sexual reproduction depends on **meiosis**, the process in which haploid gametes are formed. Meiosis involves two stages of cell division that have phases similar to those in mitosis. In mitosis, the chromosome number of the daughter cells is the same as that of the parent cell. In meiosis, the chromosome number of the daughter cells is half that of the parent cell. For example, a human cell containing 46 chromosomes that undergoes meiosis will produce gametes that each have 23 chromosomes. Since these gametes have only one set of chromosomes, they are haploid. The number of chromosomes in a gamete is called the haploid number, or n; the number of chromosomes in body cells is twice the haploid number and (with the exception of species exhibiting polyploidy) is called the diploid number, or $2n$. In humans, the haploid chromosome number is 23 and the diploid chromosome number is 46. Humans are a diploid species.

The result of sexual reproduction is that offspring receive genetic material from each parent in the form of haploid gametes. When combined, two gametes produce a zygote that contains one complete set of chromosomes (**Figure 2**).

What may surprise you is that you receive a nearly complete set of genetic instructions from each of your parents. Rather than contributing information for one half of your genes, each parent contributes a copy of virtually every gene. You receive one version from your father and one version from your mother. For example, both of your parents give you a gene containing information for eye colour. That information might be the same—instructions for blue eyes from both parents—but it could also be different—brown eye information from one parent and blue eye information from the other parent. In this way, each parent contributes one version of genetic information for each corresponding gene. Each of the 23 chromosomes you receive from your father is matched by 23 chromosomes from your mother. The paired chromosomes are called homologous chromosomes. With the exception of a pair of special sex chromosomes, which we will examine later, **homologous chromosomes** are similar in size and shape and carry genetic information for the same genes (**Figure 3**).

Fertilization occurs when a haploid sperm cell ($n = 23$) unites with a haploid egg cell ($n = 23$) to form a diploid zygote ($2n = 46$). The zygote then begins a process of ongoing growth, mitotic cellular division, and cell specialization that will ultimately produce a mature multicellular individual.

meiosis a two-stage cell division in which the resulting daughter cells have half the number of chromosomes as the parent cell; results in the formation of gametes or spores

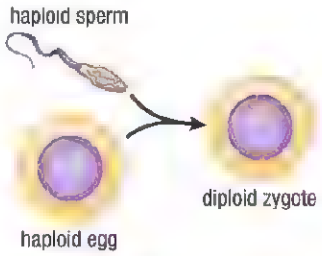


Figure 2 Fertilization results in a zygote that has two sets ($2n$) of chromosomes—one set from each parent.

homologous chromosomes matching pairs of chromosomes similar in size and carrying information for the same genes

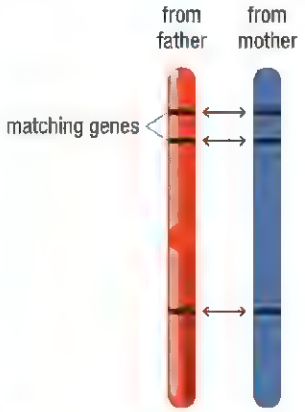


Figure 3 Homologous chromosomes carry information for the same genes.

Stages of Meiosis

Meiosis involves two divisions that produce four haploid cells. Meiosis I, the first division, is often described as a reduction division because the diploid, or $2n$, chromosome number is reduced by half to the haploid, or n, chromosome number. This reduction in chromosome number is a key distinguishing feature of meiosis. In the second division, meiosis II, the number of chromosomes is unchanged, but the total number of cells increases to four (**Figure 4**).

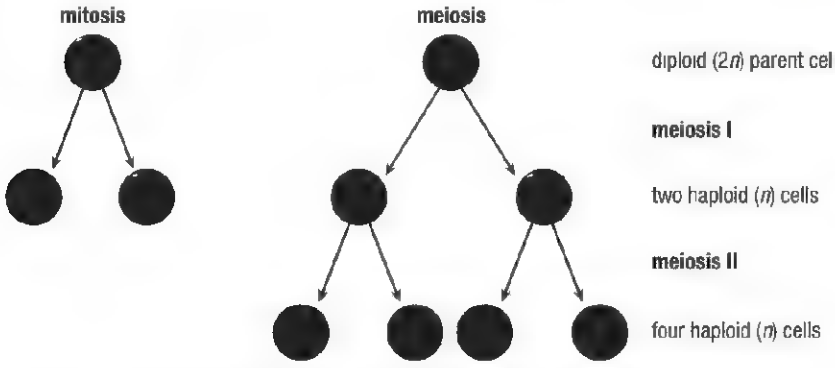


Figure 4 In mitosis, a single division results in two daughter cells with the same number of chromosomes as the original parent cell. Meiosis involves two division stages resulting in four daughter cells—each with half the number of chromosomes of the original parent cell.

MEIOSIS I

As in mitosis, DNA replication in meiosis occurs during interphase (prior to the start of meiosis). At the beginning of prophase I, the chromosomes start to shorten and thicken. Each chromosome has been replicated during interphase and now consists of two sister chromatids joined at the centromere. The nuclear membrane begins to dissolve, the centrioles separate and move to opposite poles of the cell, and spindle fibres form.

As prophase I continues, the chromosomes come together in homologous pairs. Each chromosome of the pair is composed of a pair of sister chromatids. The whole structure is then referred to as a **tetrad** because each pair of chromosomes is composed of four chromatids. Each sister chromatid intertwines with a sister chromatid from its matching homologous chromosome, a process called **synapsis** (**Figure 5**).

tetrad a pair of homologous chromosomes, each with two sister chromatids

synapsis the physical pairing up of homologous chromosomes during prophase I of meiosis

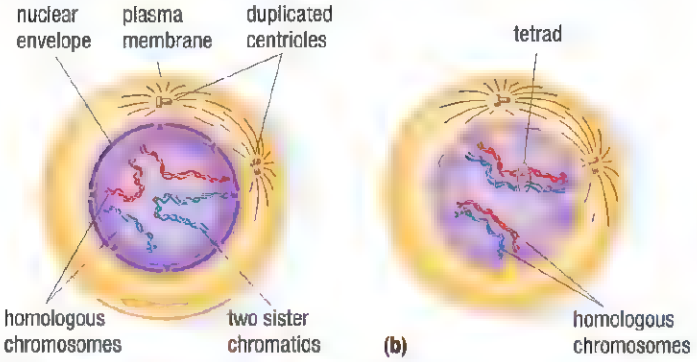


Figure 5 (a) By the end of interphase, chromosomes have been replicated. (b) In early prophase, the two pairs of homologous chromosomes in this diploid ($2n = 4$) cell have formed tetrads.

As prophase continues (**Figure 6(a)**), it is common for the intertwined chromatids from different chromosomes to break and reattach to each other—exchanging sections in a process called **crossing over**. Crossing over results in the recombination (mixing) of genetic information between non-sister chromatids of a homologous pair (**Figure 7**, next page).

crossing over the exchange of chromosome segments between homologous pairs during synapsis

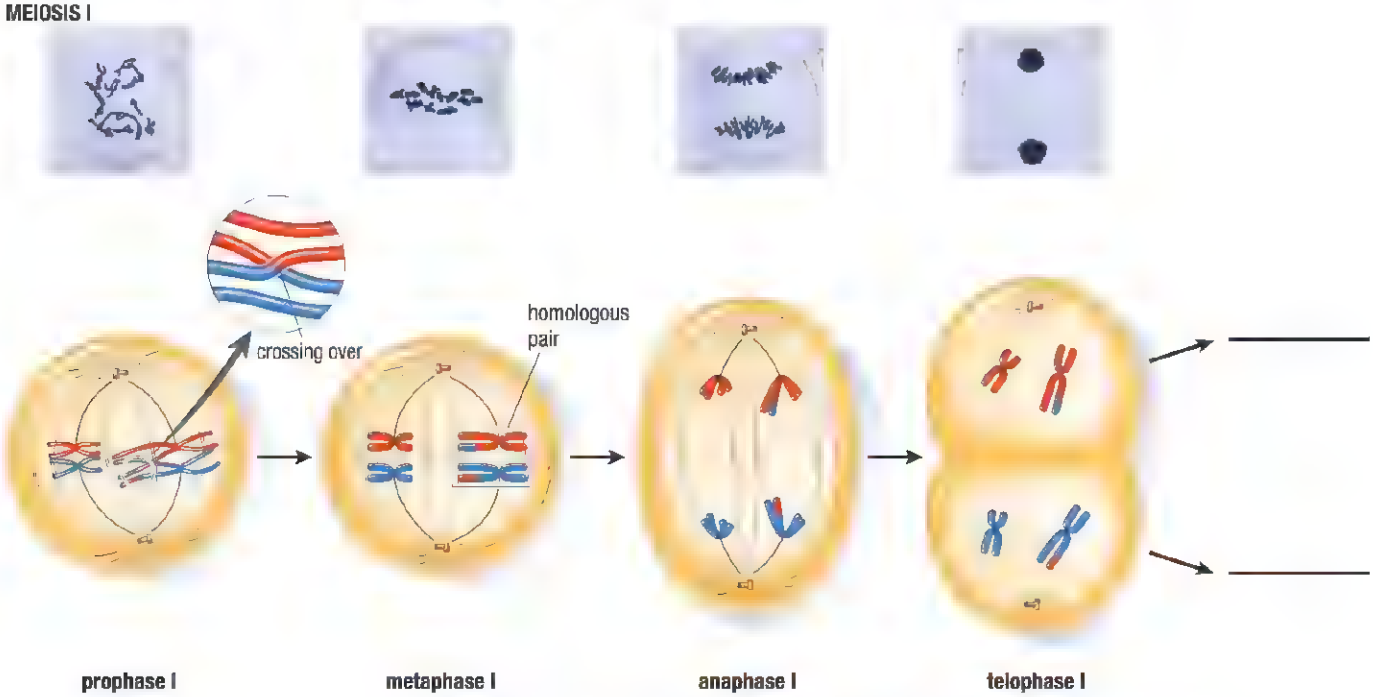


Figure 6 (a) The first meiotic division is characterized by the division of homologous chromosomes. (This diagram has been simplified to show only four chromosomes.)

During metaphase I, the tetrads (made up of pairs of homologous chromosomes) migrate toward the centre of the cell and align their centromeres across the middle of the cell.

In anaphase I, homologous chromosomes move to opposite poles of the cell. At this point in meiosis, reduction division occurs. *Only one chromosome from each homologous pair will be found in each new daughter cell.* Each chromosome in the new cells consists of two sister chromatids.

In telophase I, nuclear membranes begin to form around the chromosomes at each end of the cell and the cell begins to divide. Unlike in mitosis, the chromosomes in the two nuclei are not identical with respect to their gene content. Each daughter nucleus receives only one member of each original chromosome pair. These cells are now haploid—containing only *n* chromosomes—and are ready to begin the second stage of meiosis.

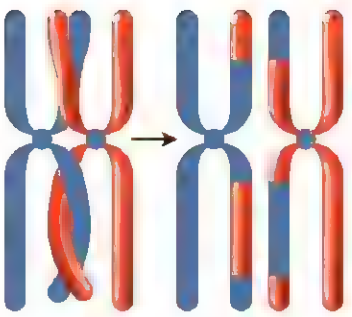


Figure 7 During synapsis, crossing over occurs and non-sister chromatids exchange segments. This results in the recombination of genetic information. For simplicity, synapsis and crossing over are shown for only two chromatids.

MEIOSIS II

Meiosis II usually begins immediately after telophase I and the first cell division (**Figure 6(b)**). Each haploid daughter cell contains one set of chromosomes. The chromosomes still consist of two sister chromatids. As a result of crossing over events, the sister chromatids are no longer identical. Note that there is no duplication of DNA between meiosis I and meiosis II.

Prophase II signals the beginning of the second division. During this stage, the nuclear membrane dissolves and the spindle fibres begin to form.

Metaphase II is identified by the arrangement of the chromosomes, each with two sister chromatids, across the middle of the cell. The sister chromatids remain attached by their centromeres.

In anaphase II, sister chromatids separate and move to opposite poles of the cell. The nuclear membrane begins to form around the chromatids, now called chromosomes.

The cells then enter telophase II, the final stage of meiosis II. During this stage, the second nuclear division is completed and the second division of cytoplasm follows.

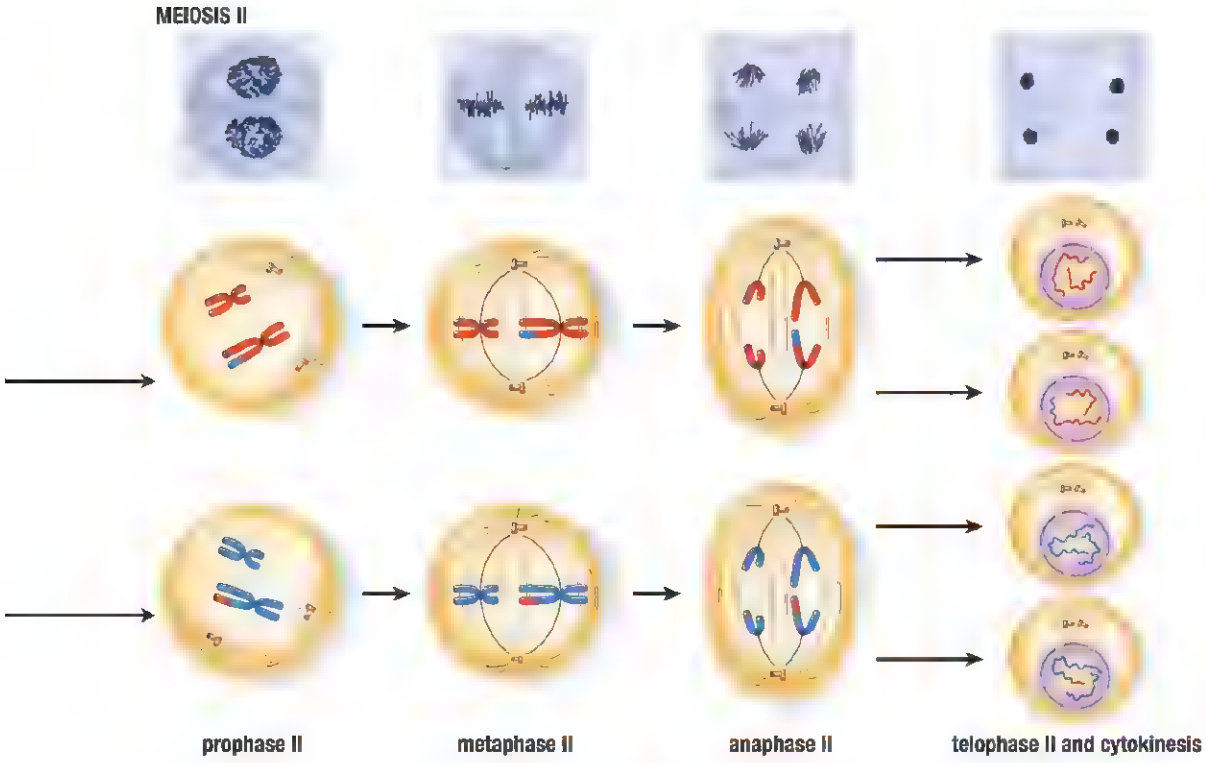


Figure 6 (b) The second meiotic division is characterized by the division of sister chromatids.

Investigation 4.3.1

Observing Meiosis (page 171)
Now that you have read about the steps involved in meiosis, you can complete Investigation 4.3.1.

In this observational study you will observe cells in the process of meiosis. You will identify the stages of meiosis and document your findings with proper biological drawings.

Four haploid daughter cells (gametes) have been produced. The recombination of genetic information that occurs during the crossing over stage of meiosis produces gametes (sex cells) that are genetically different from one another.

Random Assortment of Homologous Chromosomes

During meiosis I, homologous chromosomes pair up during prophase I and metaphase I. They are then separated from each other during anaphase I. Each daughter cell is now haploid, having received only one chromosome from each pair. When this happens, the chromosomes in each pair are assorted independently. In other words, a daughter cell can receive either chromosome of each homologous pair—this is called random assortment.

Carefully examine the four chromosome arrangements illustrated in **Figure 8**. They represent four ways in which three pairs of homologous chromosomes might be arranged during metaphase I and then separated during anaphase I. If you imagine each of these arrangements undergoing anaphase with the three chromosomes on the top moving to one pole of the cell and the three chromosomes on the bottom moving to the opposite pole of the cell, you can see that there are eight different possible combinations of chromosomes for a daughter cell. Each of these arrangements will contain one chromosome from each of the three original homologous pairs.

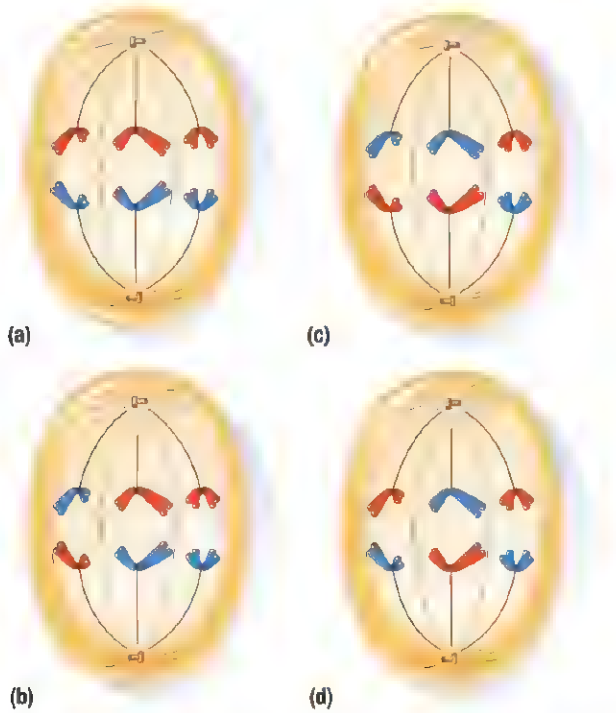


Figure 8 Four possible arrangements of three homologous pairs can occur during metaphase I. Separation during anaphase results in eight possible assortments of chromosomes in the daughter cells. Each arrangement is equally likely.

The number of possible combinations of chromosomes depends on the number of chromosome pairs. For any diploid ($2n$) organism, the number of combinations is 2^n. With three pairs of chromosomes, the number of possible combinations is $2^3 = 8$. If there are 23 pairs of chromosomes, as in humans, the number of possible combinations is $2^{23} = 8\,388\,608$!

This variation among sex cells does not include the added variation that results from crossing over. If you have ever wondered why no two people are exactly alike—even two siblings—you now have your answer!

Mini Investigation

Modelling Meiosis

Skills Menu: Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK A2.1

In this activity, you will use "pop-it" beads to represent homologous chromosomes and to model the key steps of meiosis.

Equipment and Materials: 42 red pop-it beads; 42 yellow pop-it beads; 4 twist-ties

1. Make two strings of 12 yellow pop-it beads and two strings of 9 yellow pop-it beads.
2. Use a twist tie to join the two yellow 12-bead strands together between the third and fourth beads.
3. Use a twist tie to join the two yellow 9-bead strands together between the fourth and fifth beads (**Figure 9**).
4. Make matching versions of these chromosomes using the red beads.

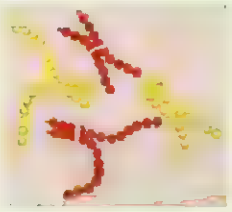


Figure 9

5. Arrange the pairs of "homologous chromosomes" side by side across the middle of your desk.
6. Perform one or two crossing over events of your choosing between non-sister chromatids.
7. Model anaphase I by separating each homologous pair—moving them to opposite ends of your desk.
8. Model anaphase II by undoing the twist-ties and separating the sister chromatids into separate locations on your desk. Each location should have one long and one short "chromosome."

A. Was your initial cell a diploid or a haploid cell? How could you tell?

B. What was *n* for these cells?

C. What event in meiosis was represented in Step 6?

D. What was the order and sequence of red and yellow beads in each of your four "gametes"?

Gametogenesis

In animals, meiosis takes place in the testes and ovaries. The formation of sex cells in meiosis is called **gametogenesis**. Sex cells contain the haploid number of chromosomes and are produced by meiosis. The production of sperm cells is called **spermatogenesis**, whereas the production of egg cells (ova) is called **oogenesis**. Although human male and female gametes both follow the general process of meiosis, some differences do exist.

In oogenesis, the cytoplasm of the female gametes does not divide equally during each of the two cell divisions of meiosis (**Figure 10**). Instead, one of the daughter cells receives most of the cytoplasm. The other cells, called polar bodies, die, and the final product of oogenesis is a single ovum (egg cell). In spermatogenesis, the cytoplasm is divided equally during each cell division, resulting in the formation of four equal-sized sperm cells. Each of the four sperm cells is small in size and streamlined for maximum motility.

gametogenesis the production of gametes (sex cells) in animals

spermatogenesis the production of mature sperm cells

oogenesis the production of mature egg cells

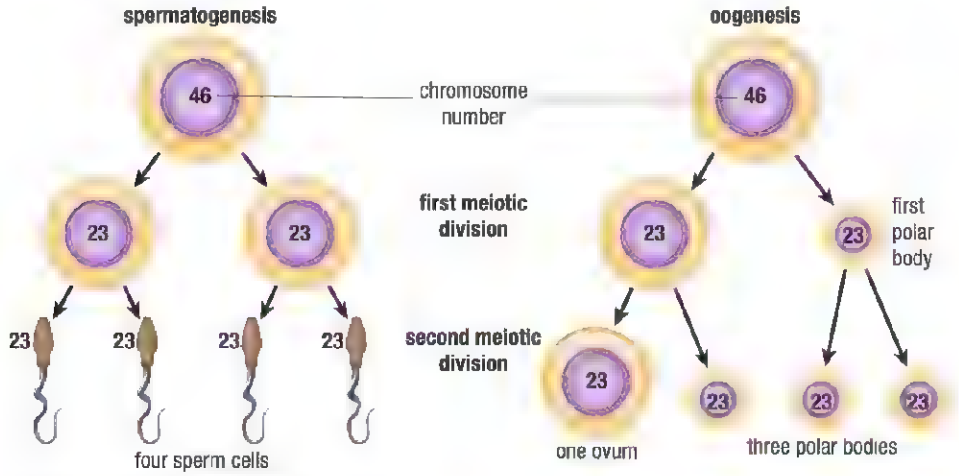


Figure 10 Spermatogenesis and oogenesis

Why are there differences between male and female gametes? Mature sperm cells must be able to swim to an egg cell in order to fertilize it. Sperm cells must be highly motile; being large and heavy would slow them down. In contrast, egg cells do not need to be motile; it is more advantageous for them to contain a large supply of nutrients in their cytoplasm. Egg cells use the nutrients and organelles carried in the cytoplasm to fuel future cell divisions in the event that the egg cell becomes fertilized.

Males produce many more sex cells than females. Once they reach sexual maturity, male humans, for example, can produce hundreds of millions of sperm cells every day. Only a few weeks after a female mammal is born, all of her potential egg cells stop developing at the end of prophase I. When she reaches sexual maturity, some of these cells go on to complete meiosis. In an entire lifetime, a female human produces between 400 and 500 eggs.

KARYOTYPES

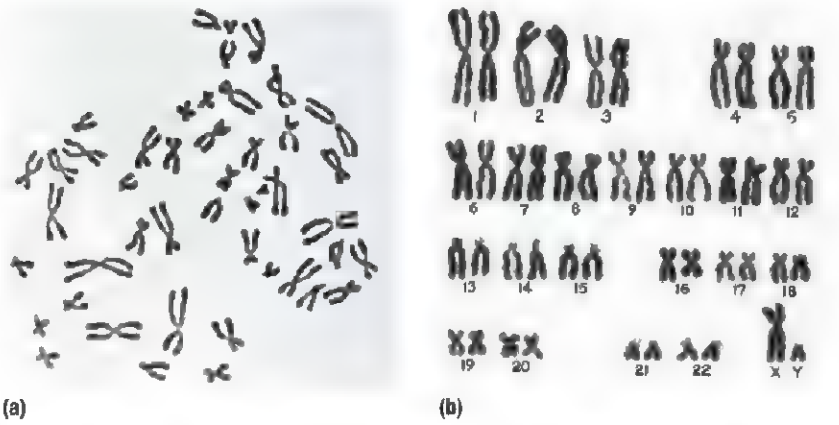
During stages of cell division, chromosomes can be stained, viewed, and photographed under a microscope (**Figure 11(a)**). Doing this allows scientists to count, compare, and arrange the chromosomes according to their size and type. A picture of chromosomes that have been arranged according to number, size, shape, or some other characteristic is called a **karyotype** (**Figure 11(b)**).

karyotype the chromosomes of an individual that have been sorted and arranged according to size and type

WEB LINK

To gain further practice in constructing and interpreting karyotypes,

GO TO NELSON SCIENCE



(a) (b)

Figure 11 (a) After all chromosomes from a single human cell are stained and photographed, (b) they can be arranged into a karyotype based on their characteristics.

Sex Chromosomes and Sex Determination

Many eukaryotic organisms, including most animals, have at least one pair of chromosomes that differ between the males and females of that species. In most mammals, for example, **sex chromosomes** consist of a matching pair of homologous chromosomes in females and a partially matching pair in males (**Figure 12**). In males, one chromosome is much smaller than the other. The larger of the two chromosomes is a homologue to the sex chromosomes in the female.

sex chromosomes chromosomes that differ in males and females of the same species; the combination of sex chromosomes determines the sex of the offspring

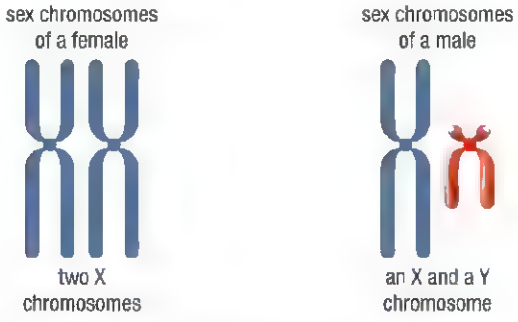


Figure 12 Sex chromosomes of a female and of a male

The larger type of chromosome is called an X chromosome, while the smaller chromosome is called a Y chromosome. Although they differ dramatically in size, parts of the X and the Y chromosomes contain matching regions that enable them to undergo synapsis and behave as a homologous pair during meiosis. Chromosomes that are not sex chromosomes are referred to as **autosomes**.

autosomes non-sex chromosomes

This pattern of XX sex chromosomes in females and XY sex chromosomes in males is referred to as the XX/XY sex determination system. This system occurs in humans and almost all other mammals. Individuals that inherit an X chromosome from their father and an X chromosome from their mother develop into females. Individuals that inherit a Y chromosome from their father and an X chromosome from their mother develop into males.

The XX/XY system is only one of many systems used by living things to determine the sex of the offspring. In many reptiles, for example, the gender of the offspring is determined by the temperature of the eggs during incubation. In some fish species, offspring are born female and become male, while in others, they are born male and become female. **Table 2** outlines some different animal sex-determination systems.

Table 2 Common Sex-Determination Mechanisms in the Animal Kingdom

Sex determination	Examples	Description
XX/XY	mammals, some insects	XX females, XY males
ZW/ZZ	birds	ZW females, ZZ males
temperature	turtles, crocodiles	If the eggs are kept relatively warm, most or all eggs hatch as females. If the eggs are kept relatively cool, most or all eggs hatch as males.
age	some fish, some mollusks	All young are born male. As they become older and larger, they change into females.
social structure	some fish	All young fish are females. When the dominant male fish dies, a large female changes into a male.
fertilization—haploic/diploid	bees, ants, wasps	Fertilized eggs ($2n$) become females. Unfertilized eggs (n) become males.
infection	some insects	Variable. In one form, infected individuals develop into females.
none	earthworms and other hermaphroditic organisms	All individuals have both male and female reproductive organs.

4.3 Summary

- Sexual reproduction produces genetically variable offspring by combining the genetic information from two parents.
- During meiosis I, chromosomes exchange genetic information, known as crossing over, during prophase I.
- Homologous chromosomes are assorted independently of other pairs.
- The formation of genetically variable sex cells in meiosis II is called gametogenesis.
- There are many different sex-determination systems in living things.
- Mammals have X and Y sex chromosomes and use an XX/XY system for female/male sex determination.

UNIT TASK BOOKMARK

What evidence suggests that the disorder you are investigating is genetic? How does meiosis account for the fact that not all offspring inherit the same disorder?

4.3 Questions

1. Not all species have distinct males and females. Describe the male and female relationships and fertilization methods in
   (a) giant clams
   (b) honeybees
   (c) earthworms
   (d) parrot fish K/U
2. Use a format of your choice to compare mitosis and meiosis. You may choose a graphical organizer or a table. You could also create a song or skit to highlight key similarities and differences. K/U C
3. How do each of the following contribute to genetic variation in offspring? K/U
   (a) Crossing over
   (b) Random assortment of homologous chromosomes
   (c) Fertilization
4. Prior to crossing over, in what ways are homologous chromosomes similar? In what ways do they differ? K/U
5. Individuals inherit a complete set of genetic instructions from each parent. Explain how this occurs. K/U
6. Describe what happens to chromosomes in each of the following phases of meiosis: K/U
   (a) prophase I
   (b) anaphase I
   (c) anaphase II
7. Copy and complete **Table 3**. K/U T/I C
   (a) Compare the chromosome number in the organisms before, during, and at the end of meiosis.
   (b) Indicate whether the chromosome number is haploid or diploid.
8. At what point in meiosis do cells change from being diploid to being haploid? K/U
9. How many different arrangements of chromosomes are possible in gametes if the cell at the beginning of meiosis has 10 chromosomes? K/U
10. Use a Venn diagram to compare spermatogenesis and oogenesis. K/U C
11. How can it be beneficial for an organism to produce only one large egg cell during oogenesis and have three polar bodies that die? In contrast, how can it be beneficial for males to produce very large numbers of very small sperm? K/U
12. Sex-determination systems are extremely diverse. Conduct Internet research to investigate and describe sex-determination in the green spoonworm (*Bonellia viridis*). INT
13. At the beginning of this chapter, you performed a Mini Investigation called Variability—It's a Coin Toss. Review the results of this activity. K/U
    (a) How did the activity model the process of random chromosome assortment that occurs during meiosis I?
    (b) How many homologous pairs of chromosomes did the investigation model?
    (c) If a cell had the same number of homologous chromosomes, how many different sex cells are possible?

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Table 3

	Human	Earthworm	Hedgehog	Broccoli
Before Meiosis				
chromosome number (haploid or diploid)	46	?	?	?
number of pairs of homologous chromosomes	?	?	45	?
After Meiosis I				
chromosome number (haploid or diploid)	?	18	?	?
After Meiosis II				
chromosome number (haploid or diploid)	?	?	?	9
number of pairs of homologous chromosomes	0	?	?	?

Abnormal Meiosis and/or Fertilization

4.4

Factors that interfere with meiosis and/or fertilization can contribute to genetic disorders and infertility. Random meiotic errors, disease, and environmental factors can result in either the inability to produce adequate numbers of viable gametes or gametes that do not carry the normal complement of genetic material.

Abnormal Meiosis: Non-disjunction

On rare occasions, during meiosis, entire chromosomes are lost or gained from cells. When this occurs, it is usually a result of non-disjunction. **Non-disjunction** occurs when homologous chromosomes fail to separate during meiosis. The result is that one of the daughter cells will have an extra chromosome, while the other will be missing a chromosome (**Figure 1**). Cells that have an extra chromosome (extra genetic material) or that are missing a chromosome (missing genetic material) are not able to function normally.

non-disjunction the failure of homologous chromosomes to move to opposite poles of the cell during meiosis; results in an abnormal number of chromosomes in the daughter cells

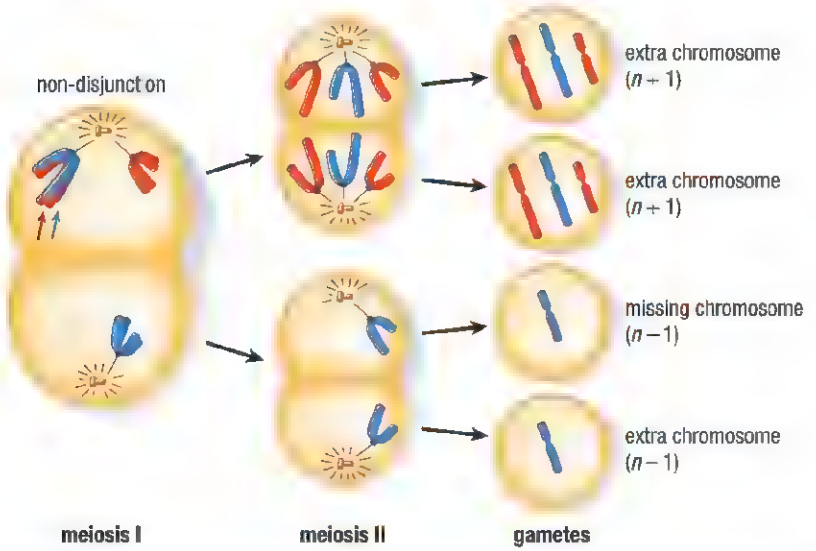


Figure 1 Non disjunction of homologous chromosomes during meiosis I results in two gametes with one extra chromosome ($n + 1$) and two gametes that are short one chromosome ($n - 1$).

In humans, non-disjunction results in gametes with 24 or 22 chromosomes. Consider the implications for the offspring. If a gamete with 24 chromosomes joins with a normal gamete (having 23 chromosomes) from the opposite sex, the resulting zygote will have 47 chromosomes instead of 46 (the normal chromosome number). The zygote will have 22 pairs of chromosomes and three copies of one chromosome, a chromosomal abnormality referred to as **trisomy**. However, if a gamete with 22 chromosomes joins with a normal gamete (having 23 chromosomes) from the opposite sex, the resulting zygote will have 45 chromosomes. Although the zygote will have 22 pairs of chromosomes, it will be missing one of its homologous chromosomes for the remaining pair, a genetic abnormality known as **monosomy**. If the zygote survives, each cell that it produces by mitosis as the embryo grows will retain this chromosomal abnormality.

trisomy a chromosoma abnormality in which there are three homologous chromosomes in place of a homologous pair

monosomy a chromosomal abnormality in which there is a single chromosome in place of a homologous pair

Non-disjunction Disorders

Down syndrome a chromosomal abnormality in which an individua has three copies of chromosome number 21; also referred to as trisomy 21

Non-disjunction is responsible for a variety of human genetic disorders, including Down syndrome, Turner syndrome, and Klinefelter syndrome. **Figure 2** compares the karyotype of a normal female with that of a female who has **Down syndrome**—a chromosomal abnormality in which there is an extra chromosome number 21. (Recall that autosomal chromosomes are numbered according to size.) For this reason, Down syndrome is also called trisomy 21.

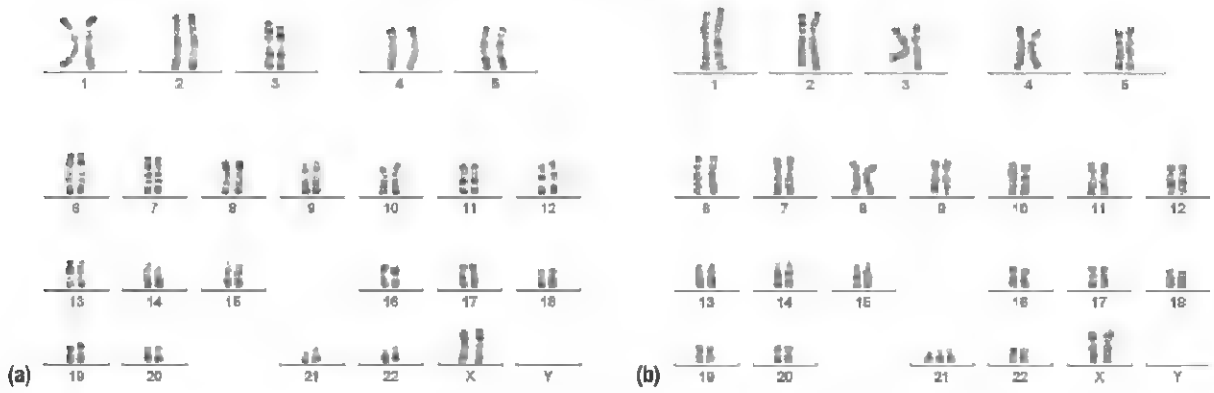


Figure 2 A karyotype of (a) a normal female and (b) a female with Down syndrome (trisomy 21)

The extra chromosome means that there is excess genetic information and an unpaired chromosome in every cell. The complications cause individuals with Down syndrome to experience both physical and mental challenges. Common traits among people with Down syndrome may include a round, full face; short height; and a large forehead. Although Down syndrome is associated with developmental and intellectual disabilities, people with Down syndrome maintain a wide range of abilities and are generally able to carry out rich, fulfilling lives.

It is believed that approximately 1 in 800 live births produces a child with Down syndrome. The probability of having a baby with Down syndrome increases with age. For example, a woman in her forties has a 1 in 40 chance of having a child with Down syndrome, whereas a woman in her twenties has only a 1 in 1000 chance.

Table 1 describes some additional human non-disjunction disorders.

Table 1 Selected Human Non-d sjunction Disorders

Non-disjunction disorder	Chromosome abnormality	Characteristics of the disorder
Turner syndrome	one X and no Y sex chromosome	Approximately 1:2500 female births. Female in appearance but do not mature sexually and are sterile. Most Turner syndrome fetuses are miscarried before the 20th week of pregnancy.
Klinefelter syndrome	two X and one Y sex chromosome	Approximately 1:500 male births Males are usually sterile and exhibit some feminine body characteristics, but severity varies.
Patau syndrome	trisomy of chromosome 13	Approximately 1:25 000 live births. Many serious developmental problems, including brain, k dney, and heart defects. Children rarely live more than a few months.
Edwards syndrome	trisomy of chromosome 18	Approximately 1:6000 live births. Many organ system defects. Very low survival rate. Most fetuses die before birth. Average life expectancy of live-born infants is less than one month.

Investigation 4.4.1

Interpreting Karyotypes (page 172)
Now that you have read about karyotyping you can complete Investigation 4.4.1.

In this observational study, you will prepare and analyze a karyotype using images of human chromosomes.

Diagnosing Non-disjunction

Non-disjunction disorders are usually confirmed by preparing a karyotype. Technicians usually prepare a karyotype by obtaining and mixing a small sample of white blood cells with a solution that stimulates mitotic division. A different solution is added that stops division at metaphase, when the chromosomes are most condensed and can be photographed and sorted. The completed karyotype is then examined and the disorder is diagnosed.

PRENATAL TESTING

A number of genetic disorders can be detected in a fetus or embryo prior to birth. Testing for a genetic disorder prior to birth is called **prenatal testing**. Testing for non-disjunction and other chromosomal abnormalities is often recommended for pregnant women over the age of 35 due to the increased risk associated with age. Prenatal testing for chromosome abnormalities often requires collecting and observing fetal cells, which can be obtained in a number of ways. As early as eight weeks into a pregnancy, the chorionic villus sampling (CVS) technique can be used to remove cells from the outer membrane (chorion) surrounding the embryo. Once the fetus is large enough, it becomes possible to obtain cells from the fluid-filled sac that surrounds the fetus, a technique called amniocentesis. Amniocentesis involves the use of a long syringe and an ultrasound machine (**Figure 3**). The collected cells are then used to prepare a karyotype chart.

Prenatal testing can also be accomplished without the need for obtaining fetal cells. Between the 15th and 20th weeks of pregnancy, women have the option of undergoing a blood test called multiple marker screening, which tests for hormone levels. Certain medical conditions correspond to a particular hormone, and performing a multiple marker screening test will identify if high levels of that particular hormone are present. If the woman's placenta has produced the hormone, it indicates an increased risk for that birth defect. Multiple marker screening can be used to test for Down syndrome and spina bifida (a malformation of the neural tube).

CAREER LINK

Genetic Counsellor

Genetic counsellors identify genetic patterns that can lead to disease and health problems for families and individuals. They help people to assess their options to make informed decisions about their future. To learn more about being a genetic counsellor,

GO TO NELSON SCIENCE

prenatal testing testing for a genetic order that occurs prior to birth

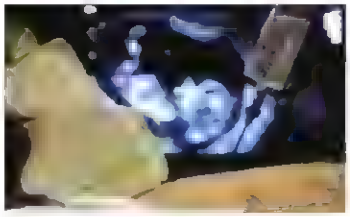


Figure 3 During an amniocentesis, fluid from the amniotic sac is extracted with a large syringe. An ultrasound machine is used to guide the syringe away from the fetus.

Problems with Fertilization

Much more common than a chromosome abnormality is the inability to conceive a child. In Ontario, approximately 10 % of couples who are trying to conceive experience problems. Of these cases, approximately one-third are attributed to the female and one third to the male. The remaining one third are ascribed to both individuals or are of an undetermined cause. There are many possible causes of infertility. They include poor or reduced egg and sperm quality and production, blocked fallopian tubes in women, and blockage in either the epididymis or vas deferens of the male.

Assisted Reproductive Technologies (ARTs)

Assisted reproductive technologies (ARTs) are technologies used to enhance the chances of reproductive success. ARTs can be used to increase sperm and egg production, improve the chances of successful fertilization, and enhance the likelihood of implantation and development. An assisted reproduction program may involve the use of fertility drugs and the sourcing, selection, and manipulation of eggs, sperm, and/or embryos outside the human body.

IN VITRO FERTILIZATION (IVF)

Conventional in vitro fertilization (IVF) treatment involves the stimulation of the ovaries using hormonal medications (in order to increase egg production), the retrieval of ova (eggs) from the ovaries, the fertilization of the eggs outside the body, and the transfer of the resulting embryo into the uterus, where, it is hoped, the embryo will implant and mature.

As science and technology advance, more and more techniques are being made available to increase the success rates associated with in vitro fertilization. Two of these are intracytoplasmic sperm injection (ICSI) and laser-assisted hatching (LAH).

Intracytoplasmic sperm injection is a form of IVF that involves the injection of a single sperm directly into the cytoplasm of an egg (**Figure 4(a)**).

IVF procedures result in disorders that cause the zona pellucida to be stiffer than normal. When sperm and eggs are combined using IVF procedures, the zona pellucida (the shell surrounding the fertilized egg) hardens, which can make it more difficult for the embryo to implant. Laser-assisted hatching is a technology designed to improve the efficiency of reproductive technologies such as ICSI. Using a precision laser, an opening is made in the zona pellucida. This weakens the wall of the embryo and helps the embryo hatch from the zona pellucida so that it can implant correctly (**Figure 4(b)**).

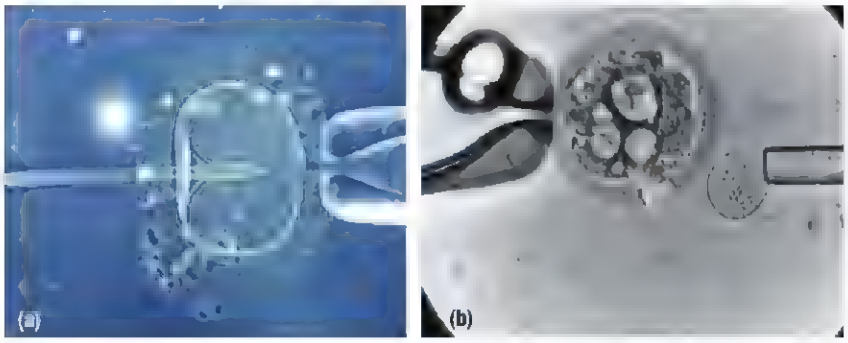


Figure 4 (a) An egg cell is being directly fertilized by the injection of a single sperm using a micropipette. (b) The relatively thick zona pellucida is being reduced on the bottom right side of the embryo. A laser targeting circle is used to precisely aim before firing a high-energy laser pulse.

ARTIFICIAL INSEMINATION

Artificial insemination (AI) is the placement of sperm into the reproductive tract of a female. In humans, this process is referred to as intrauterine insemination. A sperm sample from the donor male is "washed" to concentrate the sperm, which are then inserted directly into the uterus. Fresh or previously frozen sperm can be used.

Research This

Possible Causes of Infertility

Skills: Researching, Identifying Alternatives, Analyzing, Communicating, Evaluating

SKILLS HANDBOOK A2.1, A5.1

There is growing concern about increasing levels of infertility in many otherwise healthy populations. There are many possible factors contributing to the problem. These include environmental contaminants, undiagnosed transmitted diseases, smoking, and cultural factors, such as waiting to have children later in life. The subject is an area of active research.

In this activity you will research the current understanding of these contributing factors.

1. Use the Internet to research probable and/or suspected causes of male and female infertility.
2. Include government health agencies in your search.
3. Research information regarding the trends in infertility in the Ontario population.
4. Summarize your findings and tabulate them in an appropriate format, such as a table.

A. Which causes are of the greatest concern? T/I A

B. Which of the suspected causes are most readily treated or avoided? T/I A

C. In small groups, discuss your findings. How serious an issue do you think this is? T/I C A

GO TO NELSON SCIENCE

Implications of Reproductive Technologies

Advances in science and technology are providing insights into the underlying causes of human reproductive disorders and new methods of treating and overcoming them. Many of these same advances are being applied to non-human organisms.

However, intervening in natural reproductive processes is highly controversial. Many people and organizations have significant ethical and moral concerns regarding some, or any, reproductive technologies. Many of these concerns are most strongly held with regard to applying these technologies to humans rather than other species. Regardless of your own position on these important questions, it is valuable to have an understanding of the science behind such technologies and their applications.

Non-human Applications of Reproductive Technology

Many reproductive technologies are being applied to animal breeding and wildlife conservation efforts. Artificial insemination (AI), for example, is used in the breeding of livestock, pets, captive wild animals, and even honeybees. In fact, artificial insemination has been used extensively in agriculture for many decades.

The primary purpose of using AI in non-human applications is to enhance genetic diversity and reduce the costs involved. The genetic diversity of a herd can easily be enhanced using artificial insemination. A breeder can select the frozen sperm from a catalogue of thousands of available male donors. It is much less costly to ship a canister of frozen semen around the world than it is to ship a prize stallion for stud.

Artificial insemination is also a valuable tool in efforts to save endangered species. Giant pandas are one of the world's most critically endangered species. Unfortunately, reproductive rates are low, even in the wild, and in captivity, males and females often show little or no interest in breeding. To date, Chinese scientists have produced over 100 baby pandas using artificial insemination (**Figure 5**).

CAREER LINK

Careers in Reproductive Technology

Advances in reproductive technologies and their application provide many fascinating career opportunities in agriculture, forestry, conservation biology, and veterinary medicine. To learn more about specific careers in these fields,

GO TO NELSON SCIENCE

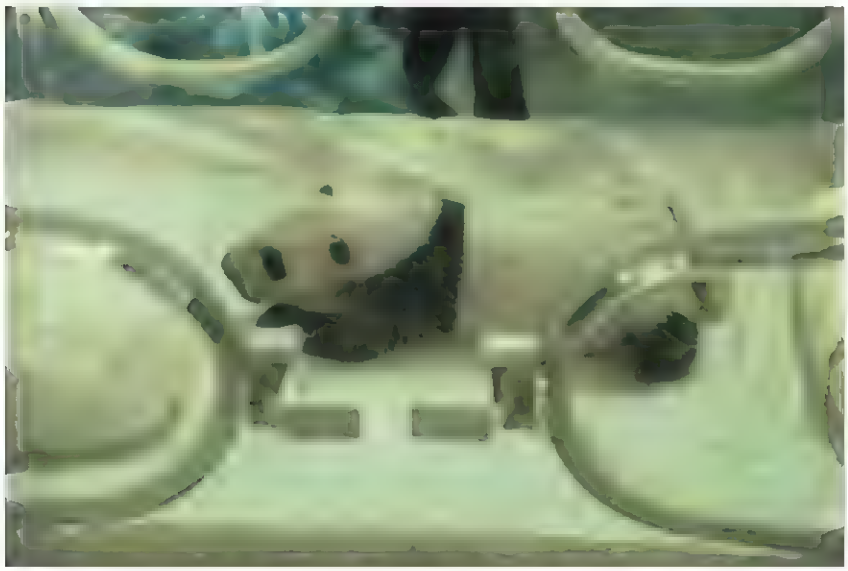


Figure 5 A baby giant panda born at the Chengdu research facility in China

The benefits of artificial insemination include the following:

- Semen can be frozen and stored for extended periods of time.
- By obtaining semen from many different animals, a "bank" of genetic information can be preserved.
- Transportation costs are low compared to moving live animals for breeding.
- It permits the breeding of animals that do not breed successfully in captivity.

One serious concern is that efforts to preserve the genetic diversity of endangered species in frozen "banks" may undermine efforts being made to preserve the species in the wild. Creating gene banks and related technologies, such as cloning, can be extremely expensive. Many people feel that the money spent on these efforts could be put to better use by helping to protect wild populations and their natural habitat.

4.4 Summary

- Errors in meiosis, including non-disjunction, can result in abnormal numbers of chromosomes and can cause serious genetic disorders.
- Karyotypes can be used to evaluate chromosome numbers and diagnose genetic disorders.
- Prenatal testing can be used to determine the likelihood of certain genetic disorders.
- Assisted reproductive technologies may be used when a couple is infertile in order to enhance their chances of conceiving a child.
- There are many applications of reproductive technologies in agriculture, industry, and wildlife conservation.
- The use of many reproductive technologies is highly controversial.

UNIT TASK BOOKMARK

Is there any evidence that the genetic disorder you are investigating is associated with a major chromosome abnormality? What information about prenatal testing should you include in your consultation report?

4.4 Questions

1. What is non-disjunction? How can it lead to both trisomy and monosomy? K/U
2. Why do you think there are more types of trisomy disorders than monosomy disorders? K/U T/I A
3. Amniocentesis, chorionic villus sampling, and multiple marker screening provide important information about the health of the fetus to the parents. This knowledge can help parents prepare for the possible birth of a child with a genetic disorder. A
   (a) Why are older women more likely to have these tests performed?
   (b) Do you think there should be any restrictions on their use?
4. Outline the benefits of using artificial insemination in wildlife conservation efforts. K/U A
5. How might the use of ART detract from efforts to protect natural habitats and populations living in the wild? K/U A
6. Describe the following types of assisted reproductive technology: K/U
   (a) conventional in vitro fertilization
   (b) intracytoplasmic sperm injection
   (c) laser-assisted hatching
   (d) artificial insemination
7. Describe the scale of the infertility problem in Ontario. K/U
8. Go online to learn more about the research conducted by Dr. Uchida and other Canadian geneticists. How have their findings contributed to our understanding of genetic disorders? T/I A
9. Examine the karyotype shown in **Figure 6**. K/U T/I

Figure 6

(a) What is the gender of the individual?
(b) Could this be the karyotype of a human sperm cell? Explain your reasoning.
(c) What evidence is there of non-disjunction?

GO TO NELSON SCIENCE

Cytoplasmic Inheritance

4.5

Not all genetic information is located within the chromosomes in the nucleus. DNA is also found in mitochondria and chloroplasts.

The Origin of Cytoplasmic DNA

As described in the Diversity of Living Things unit (Unit 1), both mitochondria and chloroplasts originated as prokaryotic organisms. One theory about their origin, now widely accepted in the scientific community, is that over time, each of these organisms was independently taken in by eukaryotic cells and became organelles (**Figure 1**).

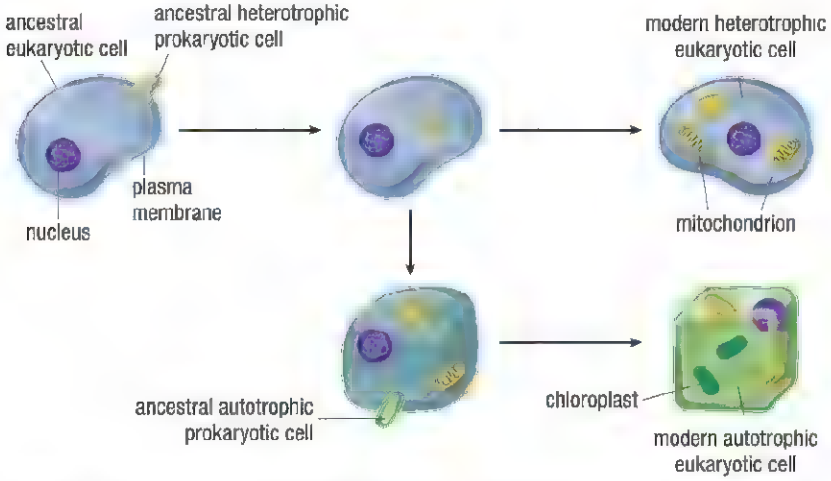


Figure 1 Mitochondria and chloroplasts originated as independent prokaryotes before becoming organelles within eukaryotic cells.

Like all prokaryotes, predecessors to modern mitochondria and chloroplasts contained their own simple chromosomes—genetic material in the form of one or more circular loops of DNA. This genetic material includes genes necessary for the proper functioning of the organelle. Without this DNA, mitochondria would not be able to carry out cellular respiration. Similarly, chloroplasts would not be able to carry out photosynthesis. Mitochondria and chloroplasts are able to reproduce independently within the cytoplasm, thereby producing copies of their DNA.

Asexual Reproduction and Cytoplasmic Inheritance

When a eukaryotic cell (or individual) is produced by asexual reproduction, each daughter cell inherits any genetic material contained within the organelles of the parent cell. As the parent cell divides, each daughter cell obtains approximately equal numbers of mitochondria and chloroplasts (if present). These organelles are assorted randomly into the daughter cells.

Sexual Reproduction and Cytoplasmic Inheritance

During sexual reproduction, each gamete contributes equal numbers of nuclear chromosomes to the zygote but does not always contribute equal amounts of cytoplasmic genetic material. Most male gametes are small and contain very little cytoplasm when compared to the large female egg cell. During fertilization, male gametes do not usually contribute organelles to the new zygote. The zygote inherits cytoplasmic DNA (mitochondria and chloroplasts) from the female gamete (**Figure 2**), a type of inheritance called **maternal inheritance**. In humans and most other animals, sperm do not contribute mitochondria to the zygote, and, as a result, the mitochondria in any individual are always genetic clones of the mitochondria of the mother.

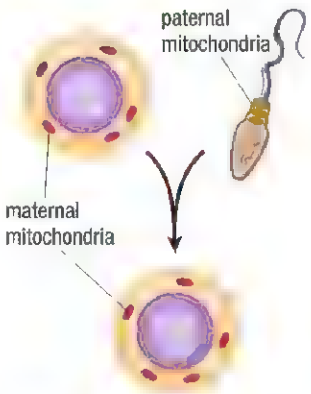


Figure 2 In sexual reproduction, human zygotes receive all of their mitochondria from the egg cell. The sperm contributes only nuclear material. This is an example of maternal inheritance of mitochondrial DNA.

maternal inheritance a type of inheritance in which a zygote formed from two gametes inherits cytoplasmic DNA from only the female gamete

paternal inheritance a type of inheritance in which a zygote formed from two gametes inherits cytoplasmic DNA from only the male gamete

Although mitochondria and chloroplasts are most often inherited maternally, this is not always the case. There are examples of **paternal inheritance**, the inheritance of cytoplasmic DNA from only the male gamete. There are also cases in which both gametes (male and female) contribute cytoplasmic DNA.

Cytoplasmic Inheritance and Genetic Variation

Although mitochondria (and chloroplasts) are normally inherited exclusively from the mother, the mitochondria (and chloroplasts) in the daughter cell are not necessarily genetically identical. For example, a plant cell might contain chloroplasts with two different sets of genetic information. These chloroplasts are separated at random during cell division, making it possible for each daughter cell to receive a different mix of chloroplasts. This genetic variability is not usually significant because, for the most part, organelles contain only a small number of genes with little or no variation.

Leaves with a variety of colours illustrate how cytoplasmic genetic variation can manifest itself. Some plants contain both normal green chloroplasts and chloroplasts with a genetic mutation that causes them to be colourless (**Figure 3(a)**).

During cell division, the random assortment of chloroplasts can produce daughter cells with a mixture of both types of chloroplasts and/or daughter cells with only a single type of chloroplast (green or colourless) (**Figure 3(b)**). When cells containing only colourless chloroplasts grow and divide, they can give rise to large patches of colourless cells in the leaf. The resulting large-scale mixture of both green cells and colourless cells is called variegation and illustrates how genetic variation and inheritance can occur within a single organism.

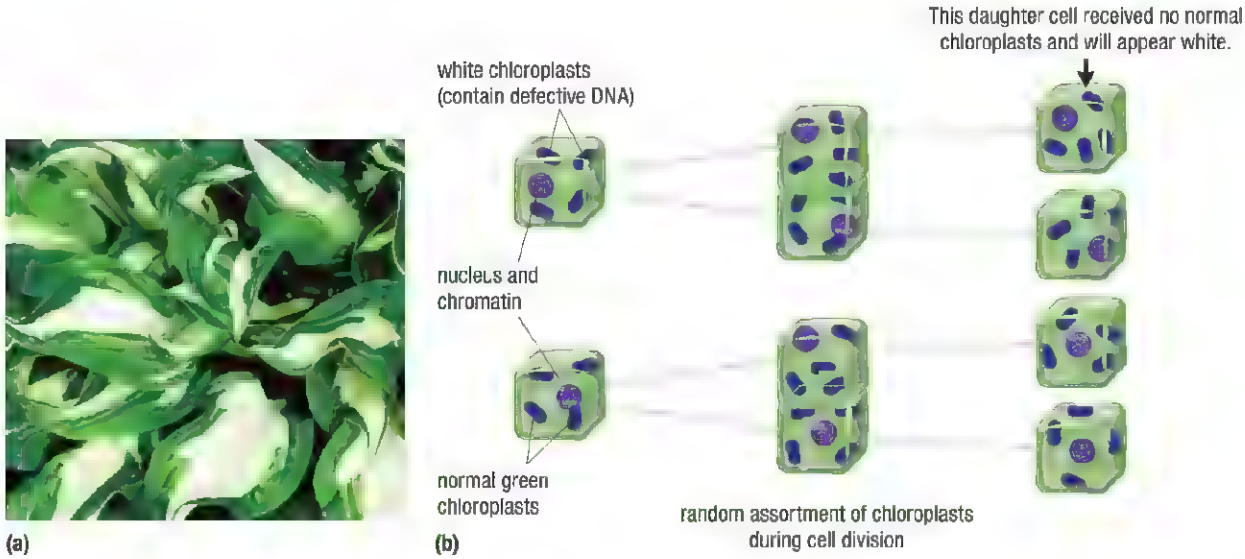


Figure 3 (a) Many varieties of hosta possess variegated leaves composed of patches of cells containing normal green chloroplasts and patches of cells containing mutant colourless chloroplasts. A gene controlling the ability to produce the green pigment is located on the DNA within the chloroplast. (b) Some plants contain both green and colourless chloroplasts. As the plant grows, it is possible for a cell to inherit only non-green chloroplasts. If this occurs, the cell will appear white. As this cell continues to grow and divide, it can give rise to large patches of white cells.

Plants with variegated leaves are valuable ornamental plants for use in horticulture. Interestingly, the random nature of chloroplast assortment means that no two plants will have identical patterns.

In humans, a number of rare genetic disorders are attributed to mitochondrial DNA. Since the genes in mitochondria often influence cellular respiration, these disorders are associated with energy metabolism. As with chloroplasts, cells may differ in the genetic content of mitochondria they contain, depending on the random assortment during cell division. Mitochondria containing defective genes may appear in some cells and not in others. The result is a complex pattern of inheritance, distribution, and disease causing influences within the cells of the individual.

DNA Egg Swapping

British scientists recently developed a very controversial method that could be used to avoid the inheritance of mitochondrial diseases. If a mother is at risk of passing on a mitochondrial disease, the nucleus of her fertilized egg could be removed and transferred to an unfertilized and enucleated egg cell with normal mitochondria from a donor female. The resulting cell would then be transplanted into the mother. The result would be an embryo with nuclear DNA from both a father and a mother, and normal mitochondria from the donor.

Part Animal, Part Plant!

The green sea slug, *Elysia chlorotica*, is a very special organism. Shaped and coloured like a leaf, the slug is an animal with the ability to perform photosynthesis (**Figure 4**). *E. chlorotica* routinely feeds on algae when it is young. However, instead of consuming and digesting the algae cells entirely, the slugs ingest the algae but keep the chloroplasts intact. The chloroplasts are taken in by cells lining the highly branched digestive system of the slug, where they become resident within the cytoplasm. The intact chloroplasts continue to perform photosynthesis, thereby providing the cells of the slug with a steady supply of food. Having obtained a good initial supply of chloroplasts, the slugs can live out the rest of their lifetime of about a year, without feeding. They can simply bask in a sunny location--acting more like a leaf than an animal!

Figure 4 The green sea slug, *Elysia chlorotica*, feeds on algae cells when it is young and keeps the chloroplasts intact and within its body cells. For the remainder of its life, the slug relies on the products of photosynthesis.

This method of obtaining food is not entirely unique among animals. Other animals have "live-in" microbes that perform photosynthesis. In corals, for example, the microbes that perform photosynthesis are completely intact cells. In the case of the sea slug, only the chloroplasts remain.

What is even more surprising to scientists is the ability of these chloroplasts to continue to function for long periods of time. Chloroplasts do not normally contain all the genetic information they need to function. Some of the genetic information needed to maintain chloroplasts is found in the nucleus of the algae cells. Amazingly, the sea slug has acquired the necessary genetic information from the algae and has incorporated it into its own nuclear DNA. This passing of genetic information from one species to another is called **horizontal gene transfer**. There is growing evidence that horizontal gene transfer may be more common than was previously thought, and this is attracting scientists to this new area of genetic research.

horizontal gene transfer the transfer of genetic information from one species into a different species

4.5 Summary

- Mitochondria and chloroplasts are organelles within the cytoplasm that contain their own genetic material.
- The genes in mitochondria and chloroplasts provide information necessary for performing cellular respiration and photosynthesis.
- The genetic information in mitochondria and chloroplasts is usually inherited maternally.
- The combination of genetic variation within organelles and the random assortment of organelles into daughter cells can produce genetic variation within the cells of individuals.
- Some observable characteristics and genetic disorders are inherited through these cytoplasmic sources of DNA.
- Horizontal gene transfer can result in one organism exhibiting a characteristic of an entirely different organism.

UNIT TASK BOOKMARK

Is there a possibility that the genetic disorder you are investigating could be an example of cytoplasmic inheritance? Why or why not?

4.5 Questions

1. Describe the genetic material of eukaryotic cells that is found outside the nucleus. K/U
2. Scientists have discovered that the DNA in mitochondria and chloroplasts is more similar to the chromosomes in bacteria than it is to the chromosomes in the nuclei of eukaryotes. How might this be explained? K/U
3. What is the role of genes in mitochondria and chloroplasts? Why are they extremely important to the survival of animals and plants? K/U
4. The genetic information in the mitochondria of 10 men was compared to the mitochondrial DNA of each of their children. None were found to be a perfect match. How can this be explained? K/U
5. Explain how genetic variation in chloroplast DNA can lead to variegation in plant leaves. How might leaf variegation be a disadvantage for plants? Can you think of any possible advantage? K/U A
6. The green sea slug is a very unusual organism. Describe how this animal has incorporated, and makes use of, genes from algae. K/U
7. Many insects are now known to have bacteria living within certain cells of their body. In some cases, both the insects and the bacteria cannot live without each other and the bacteria are passed on directly to the insect offspring. One fascinating example is that of the bacteria *Wigglesworthia glossinidia*, which lives in the tsetse fly—an insect that feeds on blood. Go online to find answers to the following questions: K/U T/I A
   (a) How do bacteria get passed from the adult tsetse flies to their offspring?
   (b) How does the tsetse fly benefit from the presence of the bacteria living within its body?
   (c) How do the bacteria benefit from living inside the tsetse fly?
   (d) Why is the tsetse fly of great significance to human health?
   (e) How would killing off the bacteria inside the tsetse fly help control the spread of disease?

CHAPTER 4 Investigations

Investigation 4.3.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Observing Meiosis

A diploid cell undergoes two divisions during meiosis, producing four haploid cells. While the large numbers of chromosomes in most cells make observation difficult, it is possible to identify the main phases of meiosis.

In this investigation, you will examine cells undergoing meiosis and document your findings by creating biological drawings. You will be examining the formation of male sex cells in lily anthers—pollen-forming flower structures—and in grasshopper testes—the site of sperm production.

Purpose

To investigate the process of meiosis through observation and to draw biological diagrams to help explain the main phases in the process

Equipment and Materials

- prepared slides (grasshopper testes, lily anther) or meiosis microslides
- microscope or microslide viewer

Procedure

1. Obtain a microscope and a prepared slide of lily anther cells undergoing meiosis. Take several minutes to carefully survey a large number of cells. This will help you locate regions where meiosis is most active.
2. Using the high-power objective lens, locate a group of cells that are undergoing meiosis (the chromosomes should be clearly visible). Once you have identified a group of cells undergoing meiosis, use the images in **Figure 1** to help you identify the various phases that they are in.
3. Create biological drawings for two or more cells undergoing meiosis. Make note of which phase of meiosis each cell is in and record this on your drawing. Be sure to properly identify and label the structures on your drawings.
4. Obtain a prepared slide of grasshopper testes and repeat Steps 1 to 3.
5. Locate a region on the slide with mature sperm cells (not undergoing meiosis). Observe several sperm cells using the high-power objective lens and create a biological drawing to record your observations.
6. If time permits, use the Internet to research images and animations of cells undergoing meiosis. You may wish to use these images as the basis for additional biological drawings.

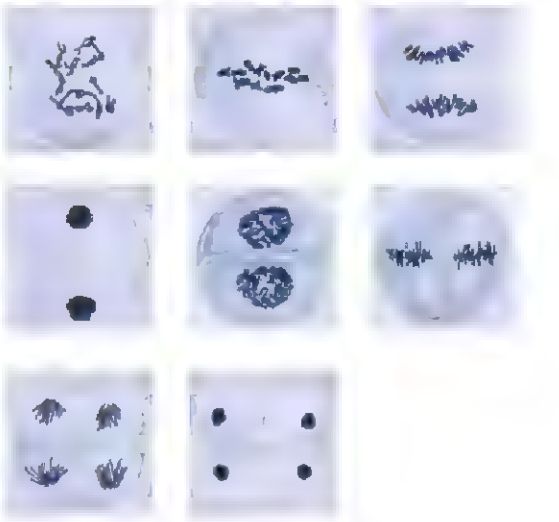


Figure 1 Photomicrographs of cells in meiosis

Analyze and Evaluate

(a) What cell structures were you able to observe in this investigation? How did you use their appearance to determine cellular activity? K/U T/I

(b) Which phases of meiosis were easiest to recognize? Explain. K/U T/I

(c) Would you have been able to accurately count the total number of chromosomes in any of the cells you observed? Explain. K/U T/I

(d) How do cells in the phases of meiosis II differ from those in meiosis I? K/U T/I

(e) Using your observations, compare meiosis in flowering plants and animals. How do the male gametes compare? What are they called? K/U T/I C

(f) What difficulties did you experience in performing this investigation? T/I

(g) Were you able to observe crossing over events? Explain why this might be difficult. T/I A

Apply and Extend

(h) Non-disjunction events are very rare. Which image in Figure 1 represents the phase during which non-disjunction could be occurring? K/U T/I A

(i) It would be impossible to observe meiosis without the use of specialized biological stains. Find out what types of materials can be used to stain chromosomes or other cell structures. T/I A

(j) In some species of grasshopper, males have 22 autosomal chromosomes and only one X sex chromosome. Females have 22 autosomal chromosomes and two X chromosomes. How do you think scientists are able to obtain this information? T/I A

(k) Research "triploid" ($3n$) banana plants. Explain why they have three sets of homologous chromosomes and how this affects their ability to undergo meiosis and sexual reproduction. T/I A

GO TO NELSON SCIENCE

Investigation 4.4.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Interpreting Karyotypes

Karyotypes can be used to determine the sex of an individual and to diagnose some chromosome abnormalities, including non-disjunction disorders. A karyotype analysis usually involves staining chromosomes with Giemsa dye. This stain produces distinctive banding patterns on the chromosomes and helps in identifying homologous pairs. The bands, however, do not represent individual genes.

In this investigation, you will evaluate a human and a non-human karyotype and use a provided sample image to model the construction of a karyotype. To simplify the very difficult task of matching homologous pairs, you will use a schematic diagram of chromosomes.

Purpose

To interpret and model the construction of karyotypes

Equipment and Materials

- schematic diagram of human chromosomes
- scissors
- glue stick

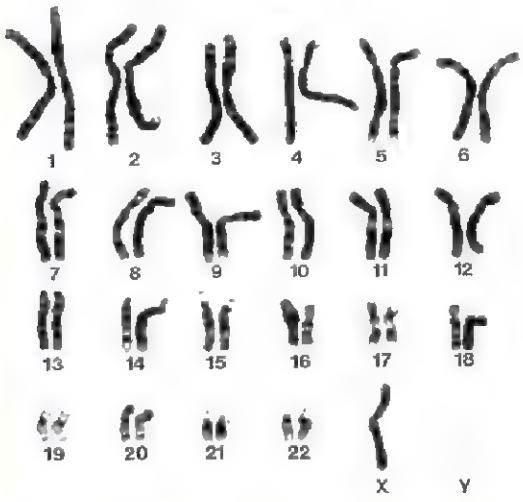


Figure 1 A human karyotype

Procedure

1. Examine the karyotype in **Figure 1**. Observe and record the number of autosomal and sex chromosomes in the karyotype. Look for any evidence of non-disjunction and record your observations.
2. Examine the karyotype in **Figure 2**. What appear to be the n and $2n$ numbers for this species?
3. Obtain a diagram of a set of chromosomes from a human cell in metaphase. Use scissors to carefully cut out each chromosome. Count and record the number of chromosomes you have.
4. Using the sizes, location of centromeres, and banding patterns on the chromosomes, match as many homologous pairs as you are able to.
5. Arrange and number the pairs from largest to smallest and glue them to a sheet of blank paper. Your final arrangement should be similar, but not identical, to the karyotype in Figure 1.

Figure 2 A non-human karyotype

Analyze and Evaluate

(a) Chromosomes vary from individual to individual and from species to species. Describe the method you used to

(i) recognize a karyotype as human (or possibly human)

(ii) determine the sex of an individual

(iii) find matching homologous pairs

(iv) provide evidence of a non-disjunction event T/I

(b) What was the sex of the individual with the karyotype shown in Figure 2? T/I

(c) Did one of the sex cells that produced this individual have an extra chromosome or have a missing chromosome? T/I

(d) What is the name for the resulting non-disjunction disorder? K/U T/I

(e) How many chromosomes would you expect to find in a sperm or egg cell of the species with the karyotype shown in Figure 2? T/I

(f) Describe the individual whose karyotype you constructed in Steps 2 and 3. K/U T/I

(g) What makes Giemsa dye so valuable when making karyotypes? T/I

Apply and Extend

(h) Describe the genetic makeup of gametes that could result in the formation of an XXY zygote. K/U T/I

(i) Why do you think trisomy zygotes are more likely to survive than monosomy individuals? T/I A

(j) It is not possible, using a karyotype, to tell homologous sex chromosomes such as XX apart from other autosomal homologous pairs. This means that the individual's karyotype in Figure 2 could be an individual of a species with no sex chromosomes or an individual with a set of homologous sex chromosomes. In this case, the karyotype in Figure 2 is of a female *Terrarana* frog from Brazil. Conduct Internet research to determine if this individual has sex chromosomes.

(k) There are millions of different species on Earth. Therefore, many species share the human characteristic of having 23 pairs of chromosomes (**Figure 3**). What features of chromosomes do you think could be used to distinguish human karyotypes from those of other species? T/I A

Figure 3 The crowned lemur (*Eulemur coronatus*) is a mammal with 23 pairs of chromosomes ($2n = 46$).

(l) Use the Internet to learn about spectral karyotypes. How do they differ from the karyotypes you have seen? How is this technology used? T/I A

GO TO NELSON SCIENCE

CHAPTER 4 SUMMARY

Summary Questions

1. Create a study guide based on the Key Concepts listed at the beginning of the chapter, on page 136. For each point, create subpoints that provide further information, relevant examples, explanatory diagrams, or general equations.
2. Look back at the Starting Points questions at the beginning of the chapter, on page 136. Answer these questions using what you have learned in this chapter. Compare your latest answers with those that you wrote at the beginning of the chapter. Note how your answers have changed.

Vocabulary

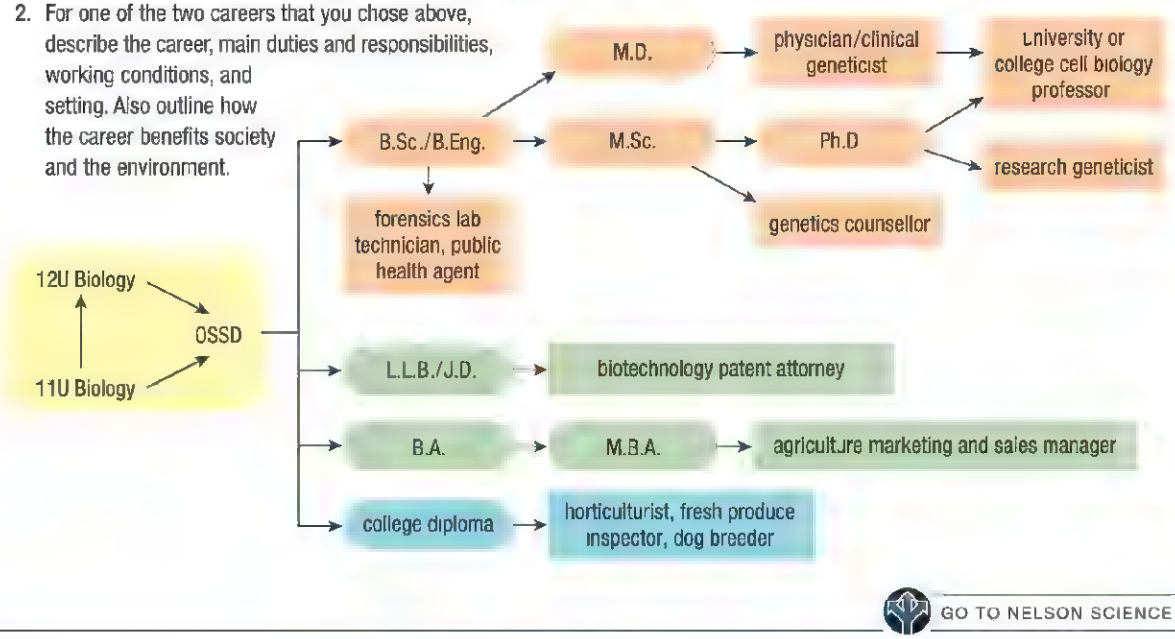
heredity (p. 138)
genetics (p. 138)
deoxyribonucleic acid (DNA) (p. 138)
gene (p. 138)
locus (p. 138)
polyploid (p. 139)
asexual reproduction (p. 139)
sexual reproduction (p. 140)
fragmentation (p. 143)
mitosis (p. 143)
interphase (p. 143)
chromatin (p. 143)
sister chromatid (p. 143)
cytokinesis (p. 145)
cloning (p. 146)
biotechnology (p. 146)
genetically modified organism (p. 148)
gamete (p. 152)
fertilization (p. 152)
zygote (p. 152)
ova (p. 152)
meiosis (p. 153)
homologous chromosomes (p. 153)
tetrad (p. 154)
synapsis (p. 154)
crossing over (p. 154)
gametogenesis (p. 157)
spermatogenesis (p. 157)
oogenesis (p. 157)
karyotype (p. 158)
sex chromosomes (p. 158)
autosomes (p. 159)
non-disjunction (p. 161)
trisomy (p. 161)
monosomy (p. 161)
Down syndrome (p. 162)
prenatal testing (p. 163)
maternal inheritance (p. 167)
paternal inheritance (p. 168)
horizontal gene transfer (p. 170)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or post-graduate degrees. This graphic organizer shows a few pathways to careers related to genetics.

SKILLS HANDBOOK A7

1. Select two careers related to genetics that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



GO TO NELSON SCIENCE

CHAPTER 4 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. How many chromosomes are found in a human somatic cell? (4.1) K/U
   (a) 6
   (b) 32
   (c) 46
   (d) 78
2. Which process is an example of asexual reproduction? (4.1) K/U
   (a) a plant producing seeds
   (b) a bird attracting a mate
   (c) a protist undergoing mitosis and cytokinesis
   (d) a dog giving birth to a litter of puppies
3. During which part of the cell cycle is genetic material duplicated? (4.2) K/U
   (a) anaphase
   (b) interphase
   (c) metaphase
   (d) prophase
4. From which group of organisms is an individual least likely to undergo asexual reproduction? (4.2) K/U
   (a) fungi
   (b) plants
   (c) protists
   (d) vertebrates
5. The process of oogenesis results in which products? (4.3) K/U
   (a) 4 egg cells
   (b) 4 sperm cells
   (c) 1 egg cell and 3 polar bodies
   (d) 1 sperm cell and 3 polar bodies
6. Chromatids from homologous chromosomes may break and recombine during which phase of meiosis? (4.3) K/U
   (a) prophase I
   (b) anaphase I
   (c) metaphase II
   (d) telophase II
7. Which genetic disorder occurs when an individual has an extra copy of chromosome 21? (4.4) K/U
   (a) Down syndrome
   (b) Edward syndrome
   (c) Klinefelter syndrome
   (d) Turner syndrome
8. An adult human with a non-disjunction disorder can have
   (a) 22 chromosomes
   (b) 46 chromosomes
   (c) 47 chromosomes
   (d) none of the above (4.4) K/U
9. Which of the following is an example of horizontal gene transfer? (4.5) K/U
   (a) Scientists breed pandas using in vitro fertilization technology.
   (b) A male human inherits cytoplasmic DNA only from his mother.
   (c) Two daughter cells receive identical genetic information from a parent cell.
   (d) A sea slug acquires genetic information from algae that it consumes.

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

10. A typical gene has hundreds, or even thousands, of chromosomes. (4.1) K/U
11. Generally, offspring produced by sexual reproduction have greater genetic variation than offspring produced by asexual reproduction. (4.1) K/U
12. The cytoplasm of a cell is divided and organelles are distributed among two daughter cells during cytokinesis. (4.2) K/U
13. Sister chromatids contain two chromosomes that contain different genetic information and are held together at the centromere. (4.2) K/U
14. Autosomes are sex chromosomes. (4.3) K/U
15. A hermaphroditic species contains individuals that produce both male and female sex cells. (4.3) K/U
16. When non-disjunction occurs during meiosis, each gamete receives an extra copy of one chromosome. (4.4) K/U
17. Organisms that reproduce asexually inherit half their genetic information from one parent. (4.1) K/U
18. Gametogenesis produces sex cells with half the number of chromosomes as a body cell. (4.3) K/U
19. The mitochondria in a human cell contain a small amount of DNA that was copied from the DNA in the cell nucleus. (4.5) K/U
20. Horizontal gene transfer involves the movement of genetic information during crossing over. (4.5) K/U

GO TO NELSON SCIENCE

CHAPTER 4 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. In what process are traits passed from parent to offspring? (4.1) K/U
   (a) heredity
   (b) genetics
   (c) fragmentation
   (d) cytokinesis
2. Which structure carries genetic information for a trait? (4.1) K/U
   (a) a gene
   (b) a chromosome
   (c) a genome
   (d) a DNA molecule
3. During interphase, what form does the genetic material in the cell take? (4.2) K/U
   (a) sister chromatids
   (b) spindle fibres
   (c) chromatin
   (d) homologous chromosomes
4. Which of the following may contain DNA from two different species? (4.2) K/U
   (a) animals produced by cloning
   (b) offspring of sexual reproduction
   (c) genetically modified organisms
   (d) daughter cells produced by mitotic division
5. Which type of organism has individuals of separate sexes and undergoes internal fertilization during the process of sexual reproduction? (4.3) K/U
   (a) earthworm
   (b) Canada goose
   (c) giant clam
   (d) willow tree
6. The somatic cells of a dog each contain 78 chromosomes. What is (are) the product(s) of gametogenesis in a male dog? (4.3) K/U
   (a) 1 sex cell containing 39 chromosomes
   (b) 2 sex cells, each containing 78 chromosomes
   (c) 4 sex cells, each containing 39 chromosomes
   (d) 4 sex cells, each containing 78 chromosomes
7. In humans, spermatogenesis and oogenesis are similar in that they both involve meiosis. How do they differ? (4.3) K/U
   (a) Spermatogenesis produces 4 functioning cells and oogenesis produces only 1 functioning cell.
   (b) Spermatogenesis produces cells with less cytoplasm.
   (c) Oogenesis produces cells that cannot move on their own.
   (d) all of the above
8. An individual with the genetic abnormality known as monosomy has
   (a) only one chromosome
   (b) an extra chromosome
   (c) a missing chromosome
   (d) only one gene in each chromosome (4.4) K/U
9. Human zygotes receive mitochondria from
   (a) only the egg cell
   (b) only the sperm cell
   (c) both the egg and the sperm cell
   (d) neither the egg cell nor the sperm cell (4.5) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

10. A human body cell has 46 chromosomes. (4.1) K/U
11. Some organisms reproduce by cell division alone. (4.1) K/U
12. Budding is a form of sexual reproduction. (4.2) K/U
13. Cell division has two stages: mitosis and cytokinesis. (4.2) K/U
14. During meiosis I, sister chromatids are separated. (4.3) K/U
15. A picture of chromosomes arranged by size, number, or shape is called a tetrad. (4.3) K/U
16. Some genetic disorders can be detected before birth by prenatal testing. (4.4) K/U
17. Mitochondria and chloroplasts reproduce independently of the cell in which they are found. (4.5) K/U
18. Maternal inheritance refers to inheritance in which offspring inherit all their cytoplasmic DNA from the female gamete. (4.5) K/U

Match each term on the left with the most appropriate description on the right.

19.

(a) Down syndrome	(i) trisomy of chromosome 18
(b) Edward syndrome	(ii) trisomy of chromosome 21
(c) Klinefelter syndrome	(iii) one X and no Y sex chromosome
(d) Turner syndrome	(iv) trisomy of chromosome 13
(e) Patau syndrome	(v) two X and one Y sex chromosomes (4.4) K/U

20. (a) anaphase I — (i) each sister chromatid undergoes synapsis with a sister chromatid from its matching homologous chromosome
    (b) metaphase II — (ii) completion of the second nuclear division
    (c) prophase I — (iii) chromosomes, each with two sister chromatids, line up across the middle of the cell
    (d) telophase II — (iv) reduction division occurs (4.3) K/U

Write a short answer to each question.

21. What term describes a cell with three or more sets of chromosomes? (4.1) K/U
22. An adult mosquito has six chromosomes in each somatic cell. It mates with another adult to reproduce sexually. How many chromosomes do the offspring have in each somatic cell? (4.1) K/U
23. In an individual produced by sexual reproduction, what portion of the individual's genetic information comes from each parent? (4.1) K/U
24. What are the structures called "sister chromatids" that appear in a cell at the beginning of mitosis? (4.2) K/U
25. Explain how you might identify metaphase I if you were viewing cells with a microscope. (4.2) K/U
26. What technology are some people concerned will lead to the production of genetically identical humans chosen for certain desirable traits? (4.2) K/U
27. What is produced in the process of fertilization? (4.3) K/U
28. Describe the sex-determination system of earthworms. (4.3) K/U
29. What term describes a pair of chromosomes that are similar in size and shape and carry genetic information for the same genes? (4.3) K/U
30. What is the result of the process called crossing over? (4.3) K/U
31. Identify two types of organisms in which temperature affects sex determination. (4.3) K/U
32. Identify two general categories of problems that can lead to unsuccessful sexual reproduction. (4.4) K/U
33. Name two types of non-disjuntion disorders that can result during the formation of gametes. (4.4) K/U
34. Which type of assisted reproductive technology involves the placement of sperm into the reproductive tract of a female? (4.4) K/U
35. Name two genetic or congenital (birth) disorders that can be detected by analyzing the blood of the mother with a test known as multiple marker screening. (4.4) K/U
36. Name two cell organelles that contain cytoplasmic DNA. (4.5) K/U
37. What term describes the passing of genetic information from one species to another? (4.5) K/U
38. Explain the similarity between the locus of a gene and the street address of a home. (4.1) K/U

Understanding

39. (a) Describe one example of naturally occurring asexual reproduction.
    (b) Compare the genetic makeup of the offspring and parent in the example you provided. (4.1) T/I
40. (a) Describe one advantage of sexual reproduction.
    (b) Describe one disadvantage of sexual reproduction. (4.1) T/I
41. A student in a biology lab uses a microscope to observe a cell with stained chromosomes, as shown in **Figure 1**. The student uses a higher-power objective to confirm that each chromosome consists of a pair of sister chromatids. (4.2, 4.3) T/I C A
    (a) Identify the process (mitosis or meiosis) and the phase of the process that the student is observing. Provide reasoning for your answer.
    (b) Explain how you can identify the process and how you can determine the phase of the process.

Figure 1

42. The mechanism by which cytokinesis proceeds is slightly different in plant cells than it is in animal cells. (4.2) T/I A
    (a) Describe how cytokinesis proceeds in a typical animal cell.
    (b) Describe how cytokinesis proceeds in a typical plant cell.
    (c) Based on what you know about the structure of plant cells, explain why they cannot use the same method of cytokinesis that animal cells do.

43. Compare and contrast the types of individuals (male and female, hermaphrodite, or other), the types of gametes produced, and the fertilization methods of the following pairs of organisms. (4.3) K/U T/I
    (a) willow tree and bald eagle
    (b) giant clam and parrot fish
44. In most organisms, egg cells and sperm cells have differing characteristics. Compare and contrast the following characteristics of human egg and sperm cells. (4.3) K/U T/I
    (a) number of chromosomes they contain
    (b) ability to move independently
    (c) amount of nutrients they contain
    (d) number of sex cells produced during the human lifetime
    (e) stage of human life in which the sex cells are produced
45. Compare the sex-determination systems of the following paired groups of organisms, and identify the pair that has a greater similarity. Explain how you know. (4.3) T/I A
    (a) birds and turtles
    (b) birds and humans
46. Identify two mechanisms of meiosis that contribute to the genetic diversity of the gametes of an organism. Explain how they accomplish this. (4.3) T/I
47. Use **Figure 2** to answer (a) and (b). (4.3) T/I C

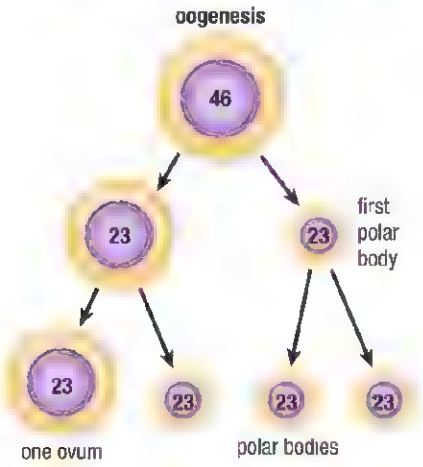


Figure 2

    (a) Describe the process shown by the diagram.
    (b) Name the two different products of the process, and explain what happens to each product.
48. (a) Draw a diagram that shows what happens when non-disjunction occurs during meiosis.
    (b) Explain what would happen if one of the resulting gametes joined with a normal gamete and developed into an individual. (4.4) T/I C
49. Identify and describe two factors that increase the chance of a human offspring inheriting the genetic characteristic for Down syndrome. (4.4) K/U A
50. Compare and contrast the following aspects of Turner syndrome and Kleinfelter syndrome. (4.4) K/U T/I
    (a) number and type of sex chromosomes in the cells of affected individuals
    (b) the cause of these disorders
    (c) characteristics of affected individuals
51. Women who have an increased risk of conceiving babies with genetic abnormalities may seek prenatal screening to gain information that can be used to determine whether a fetus has a genetic abnormality. (4.4) K/U T/I A
    (a) Explain how fetal cells can be sampled and tested for genetic abnormalities.
    (b) Explain how a blood sample from the mother can be used for prenatal testing.
    (c) Compare the benefits and risks of these two types of procedures.
52. Identify two reasons why zookeepers frequently use artificial insemination in the breeding of zoo animals. (4.4) K/U
53. Explain why DNA from mitochondria can provide information about a person's maternal lineage, but not about a person's paternal lineage. (4.4, 4.5) T/I A
54. A eukaryotic organism reproduces asexually by mitotic division. (4.1, 4.5) T/I
    (a) Explain why the nuclear DNA of the offspring will most likely be identical to that of the parent.
    (b) Explain why the cytoplasmic DNA of the offspring may not be identical to that of the parent.
55. The mitochondria in your body cells contain a relatively small number of genes. (4.5) T/I
    (a) Explain why your mitochondria contain their own genes.
    (b) Describe how you inherited these mitochondrial genes.
56. Describe the process of DNA egg swapping. Identify the types of diseases it could be used to prevent. (4.5) K/U

Application

57. A biologist used the following phrase to describe a form of reproduction: "Costly to individuals; beneficial to species." T/I A
    (a) What type of reproduction is this scientist describing?
    (b) Why is this type of reproduction described as "costly to individuals"?

(c) Why is this type of reproduction described as "beneficial to species"?

(d) Is this type of reproduction equally beneficial to species in all environments? Explain.

58. A rancher wants to increase the genetic diversity of her herd of cattle. She orders frozen semen from bulls from another herd and uses that semen to artificially inseminate some of her cows. (4.1, 4.4) T/I A

(a) Explain why the rancher would want to increase the genetic diversity of her herd.

(b) Describe one benefit of using artificial insemination instead of breeding cows without the use of assisted reproductive technology.

59. In 1958, biologist Frederick Steward published his technique for cloning carrot plants from a mature adult carrot cell. However, it was not until 1996 that scientists first successfully cloned a mammal, a sheep named Dolly, from a mature adult cell. (4.2) K/U T/I A

(a) Describe the process Steward used to clone carrot plants.

(b) Describe the process scientists used to clone Dolly.

(c) Explain why it took so long after the development of plant cloning techniques for scientists to learn how to clone an adult mammal.

60. Cloning technology is currently used for many different applications. Describe one use of cloning technology in each of the fields below:

(a) agriculture

(b) medicine

(c) conservation

(d) industry (4.2) K/U A

61. A student wishes to make a model of meiosis that could be used to help younger students visualize the process. She decides to use coloured jellybeans to represent cells in her model; blue represents diploid cells and green represents haploid cells. (4.3) T/I A

(a) How many total jellybeans does this student need to show the original cell, the results of meiosis I, and the results of meiosis II?

(b) How many blue jellybeans does this student need to complete her model? What cell or cells do these represent?

(c) How many green jellybeans does this student need to complete her model? What cell or cells do these represent?

(d) Identify one misconception that this model might promote.

62. Many species of turtle and crocodile are already endangered. A scientist hypothesizes that global climate change might adversely affect the ability of turtle and crocodile species to reproduce over a number of generations. (4.3) T/I C A

(a) Explain the probable basis for this hypothesis.

(b) Propose a conservation plan for turtles and crocodiles that would address the issue you described above.

63. In humans the sex determination mechanism is classified as XX/XY. Other organisms, such as other mammals and some insects share the same type of sex determination. (4.3) K/U T/I A

(a) In these species, identify the sex chromosomes found in a typical male.

(b) In these species, identify the sex chromosomes found in a typical female.

(c) In these species, would you expect to find a gene that coded for a protein essential to all individuals on the Y chromosome? Why or why not?

(d) Could a disease caused by a mutation in a gene found on the Y chromosome affect a female? Explain.

(e) Could a disease caused by a mutation in a gene found on the X chromosome affect a male? Explain.

64. **Figure 3** shows a karyotype produced by staining the chromosomes from a single human cell. (4.4) T/I C A

(a) Was the individual who provided the cell sample for this karyotype male or female?

(b) Explain how you can tell the sex of the individual by the karyotype.

(c) Explain how karyotypes can be used to test for certain types of genetic disorders.

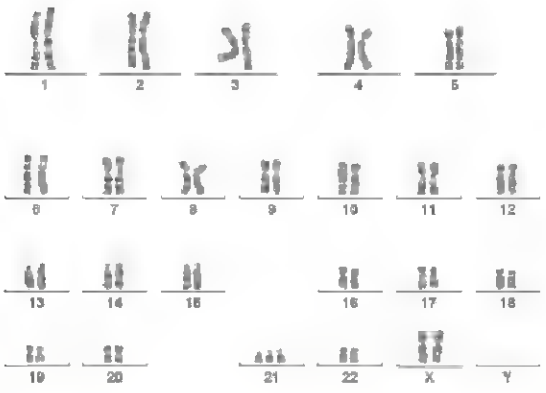


Figure 3

Evaluation

65. Male magnificent frigate birds are able to inflate a large red throat pouch (**Figure 4**). K/U T/I A
    (a) Suggest a probable use of such a feature.
    (b) Describe how such a feature might put the bird at greater risk.
    (c) You hear a student comment that the benefit outweighs the risk. Do you agree with this statement? Explain.

Figure 4

66. Jenna's mom transplanted several strawberry plants that had been produced as runners from a plant in their backyard garden into pots. When the strawberry plant in the backyard garden died because it was attacked by a garden pest, Jenna's mom took some of the plants in pots and replanted them in the backyard garden, hoping that they would be more resistant to the pests than the original plant. Explain whether Jenna's mom is correct to expect the transplanted plants to be more pest resistant. Explain your response. (4.2) T/I A C

67. Cheetahs are an endangered species. Their population was reduced by hunting and historical disruption to their habitat. There is very little genetic variation in the remaining population. Evaluate the prospects of saving the cheetah from extinction through a program of cloning. Explain whether such a program is likely to be effective in the long term. (4.2) C A

68 For centuries, farmers and plant scientists have been developing new varieties of fruits and vegetables by crossbreeding plants with desirable characteristics. (4.2) T/I C A
    (a) Explain how the practice of creating and cloning genetically modified plants differs from the practice of breeding plants.
    (b) Why are some people more concerned about the risk of creating and cloning genetically modified plants than they are about the risk of breeding new varieties of plants?

69. In some plant species, individual plants can produce both male and female flowers. In some cases, pollen from the male flower is able to fertilize an egg inside the female flower of the same plant and produce a viable seed that can grow into a new plant. (4.2, 4.3) T/I C
    (a) Explain how this process is different from asexual reproduction, even though a single plant produces offspring.
    (b) Evaluate the cost and the benefit to the plant in using this process instead of simply reproducing asexually.

70. Some scientists have proposed uses of assisted reproductive technologies (ARTs) to help preserve endangered species. (4.4) C A
    (a) Explain the possible benefits of using ARTs in conservation.
    (b) Explain the possible drawbacks of using ARTs in conservation.

71. Most discussions of genetics ignore the inheritance of cytoplasmic DNA. Suggest an explanation to account for this. T/I A

72 An individual with a mitochondrial disorder is asked whether he is concerned about passing the disease on to his future offspring. He states that none of his children will inherit his disorder. Is this statement correct? Explain why or why not. (4.5) T/I A C

73. A student was describing evidence for the theory that mitochondria and chloroplasts were once free-living prokaryotes that have become incorporated in eukaryotic cells. She mentioned the green sea slug as evidence to support this theory. Evaluate whether the green sea slug is good evidence for this theory, and justify your opinion. (4.5) T/I A C

Reflect on Your Learning

74. Different assisted reproductive technologies (ARTs) can be used to help humans and other animals conceive offspring. T/I A
    (a) Do you have any ethical concerns about the use of ARTs? Explain.
    (b) Do you feel differently about the use of ARTs in different situations? Explain.

75. In this chapter you learned about different technologies that some people object to, such as cloning and the production of genetically modified organisms. Do you think it is important to learn about these technologies even if you object to some of their applications? Explain why or why not. T/I C

76. Did you learn anything in this chapter that surprised you? Explain. T/I C

77. In this chapter you learned that when a human cell undergoes meiosis, the number of possible combinations of chromosomes in the daughter cell is 8 388 608. Does this change your thoughts about the uniqueness of the combination of traits that makes you who you are? Explain your thinking.

Research

GO TO NELSON SCIENCE

78. Although flowering plants, such as fruit trees, can reproduce sexually, many gardeners and horticulturalists prefer to propagate plants by means of asexual reproduction. T/I C A
    (a) Research methods that horticulturalists use to produce flowering plants for farms and gardens. Create a table summarizing at least three methods of asexual propagation. For each method, include a description and examples of plants typically propagated by that method.
    (b) Explain the advantage of using asexual methods to propagate plants for use in farming and gardening.
79. Many genetically engineered food crops are now grown in North America and are used in a wide variety of food products. Research genetically engineered food crops. Find out which crops are most commonly used, examples of common food products that contain genetically engineered organisms, common arguments for and against genetically engineered food crops, and which companies produce and sell genetically engineered seed. Create an informational brochure or poster highlighting the results of your research. T/I C A
80. In this chapter you learned about how Chinese scientists have used artificial insemination to produce baby pandas. Research other examples of how reproductive technologies are being used to help increase the populations of endangered or threatened species. Choose one example to present in a written report. Be sure to address the following questions in your report:
    (a) Which type of technology is being used?
    (b) How do scientists gain access to the animals used for breeding?
    (c) Where does the breeding program take place?
    (d) What happens to the offspring produced in the breeding program? T/I C A
81. In October 2010 Robert Edwards was awarded the Nobel Prize in Medicine and Physiology for his pioneering work in IVF. Do research to find out more about his work and its implications. T/I A
    (a) When and where did Dr. Edwards begin his research into reproductive technology?
    (b) When and where was the first "test tube baby" conceived by IVF born?
    (c) How many people have been born by IVF since the birth of Louise Brown?
82. *Cnemidophorus* is a genus of lizards commonly know as whiptails. The genus includes more than 10 species that are parthogenic the females reproduce asexually and there are no males. Do online research to answer the following questions. T/I A
    (a) How do these species form?
    (b) Are any of the females able to mate with other lizard species? If so, what sort of offspring result?
    (c) Based on your understanding of the benefits of sexual and asexual reproduction, would you expect these species to be more or less able to withstand environmental change? Explain your reasoning.
83. Stained chromosomes exhibit banding patterns that can be used to distinguish one chromosome from another. Photographs of the stained chromosomes can then be analyzed by computer software and displayed as schematic diagrams. K/U T/I A
    (a) Conduct research into the use of staining chromosomes.
    (b) What are the advantages of these diagrams over photographs of the actual chromosomes?
    (c) Each light band is associated with regions that have one or more genes. Describe the variability of these chromosomes in terms of banding patterns.

CHAPTER 5

Mendelian Genetics—Patterns of Inheritance

KEY CONCEPTS

After completing this chapter you will be able to

- describe the early experiments of Gregor Mendel and relate his conclusions to modern genetic theory
- solve monohybrid and dihybrid cross problems using Punnett squares, and use probabilities to determine the expected phenotypes and genotypes in the offspring
- explain and provide examples of dominance, incomplete dominance, and multiple alleles
- draw and follow a pedigree chart in order to track a specific allele through many generations
- describe genetic disorders that are caused or influenced by specific genes
- consider the social and ethical implications associated with genetic testing

How Are Genes Passed on from Parent to Child?

You have your mother's eyes, your father's curly hair, and your grandmother's disposition. How are characteristics passed on from one generation to the next? Why do characteristics disappear from one generation and then reappear in the next? Can you predict which characteristics will be inherited? Would you like to be able to predict the characteristics you will pass on to your children, or find out which ones have been passed on to you from your parents but have not surfaced yet?

Researchers in modern genetics laboratories now study how specific characteristics are passed on from parent to offspring. However, humans have studied the characteristics of plants and animals ever since the beginning of organized agriculture. Early farmers learned that selective breeding of the best individuals resulted in a better food supply. These early farmers did not know about DNA or genes. They practised genetic selection by choosing to breed plants and animals based on characteristics that were important to them. In selecting and breeding corn, for example, they considered the size, colour, and shape of corn kernels, as well as their nutritional content.

Today we have a better understanding of how genes are passed from parent to child. Geneticists are most interested in pinpointing the exact mechanism by which a gene is passed on to offspring, especially in the case of genetic diseases. For example, two parents who do not have cystic fibrosis, a genetic respiratory disease, may have a child who is born with cystic fibrosis. Did the cystic fibrosis gene come from both parents, or just one? Will all the children of these parents have cystic fibrosis, or just some? By understanding how genetic disease genes are passed on, geneticists are able to answer such questions. Once such questions are answered, researchers can work on treatment and prevention.

In this chapter you will investigate how characteristics are passed on from parent to child. You will find out how the rules of probability predict the offspring's characteristics. You will explore the idea of being able to determine which genes you carry, and the social and ethical consequences of finding out. Finally, you will see how certain characteristics may be valuable to one individual and detrimental to another.

STARTING POINTS

Answer the following questions using your current knowledge. You will have a chance to revisit these questions later, applying concepts and skills from the chapter.

1. How do you think genetic information gets passed on from generation to generation?
2. Why are some characteristics passed on from parent to child while others are not?
3. How might an understanding of genetic processes and the inheritance of biological characteristics benefit individuals and society?
4. Why is there so much variation in the human population with respect to what humans look like?
5. How does society benefit from the screening of harmful genes?

Mini Investigation

Amaizing Genetics (Or *Corny* Genetics)

Skills: Questioning, Researching, Observing, Analyzing

SKILLS HANDBOOK A2.1, A2.3

Equipment and Materials: cob of dried "Indian corn"

Corn, also called maize, is an extremely important agricultural crop with more than 800 million tons produced worldwide each year. Originally domesticated by indigenous peoples of central America, it has been the focus of much interest for thousands of years. Many of corn's traits have been intensely investigated and modified. Today, both natural and genetically engineered corn plants are grown to produce foods, livestock feeds, and biofuels. In this investigation you will examine a cob of corn and gain insights into the inheritance of a single characteristic–kernel colour.

1. Carefully examine your cob of corn. Each kernel is an individual produced by the sexual reproduction of two parent plants. A cob typically contains between 200 and 400 "offspring." Count the total number of kernels on your cob.
2. Your cob has kernels that are variable in colour. Carefully examine the order of colours along different rows of the cob.
3. Now count the total number of kernels of each colour and record them in a table.
4. Calculate the percentage of each colour type.
5. Compare your percentages with the results of other students.

A. Would you describe the order of the kernel colour along a row as predictable or as random?

B. Would you describe the percentages of the kernel colour as predictable or as random?

C. What might your observations suggest about the influence of one colour over the other? Do you think the inheritance of both colours is "equally likely"?

D. The two parent plants of these offspring grew from individual kernels. Predict the colour(s) of the parent kernels.

E. Examine the photograph at the top of this page. The corn kernel colouring is not uniform–some kernels are striped or "mosaic". A now famous geneticist was puzzled by this pattern and did research to uncover how it was inherited. Her research lead to the discovery of "jumping genes". Do online research to find out more about this geneticist and how she was rewarded for her discovery.

5.1 Mendelian Inheritance

trait a particular version of a characteristic that is inherited, such as hair colour or blood type

You are likely familiar with the notion of resemblance—two siblings who look similar to each other or to their parents. You probably resemble one or more of your family members. This is because you have many genes in common. When we talk about resemblance, we are usually referring to traits. A **trait** is a particular version of an inherited characteristic, such as a person's eye colour or the shape of a leaf. People have always recognized that traits are hereditary, even though they did not understand the mechanism of inheritance. Over the last few centuries, advances in genetics have changed the way we understand inheritance.

We owe much of our understanding of genetics to the extensive experiments conducted by Gregor Mendel in the nineteenth century (**Figure 1**). At that time, some scientists thought that traits from each parent were blended in the offspring, similar to mixing red and white paint to make pink paint. However, offspring sometimes exhibited a trait identical to that of one parent rather than blending those of both parents. To explore patterns of inheritance, Mendel crossbred thousands of plants in his garden and carefully recorded the offsprings' traits.

Figure 1 Gregor Johann Mendel (1822–1884) is known as the "father of genetics."

Mendel's Pea Plants

Mendel conducted experiments with the garden pea, *Pisum sativum*. He chose the garden pea because it reproduces quickly and, more importantly, he could control which parents produced offspring. Pea flowers have both male and female reproductive organs. Garden peas are both self-fertilizing and cross-fertilizing. In other words, the pea flower can self-pollinate (mate with itself) or pollinate others.

true-breeding organism an organism that produces offspring that are genetically identical for one or more traits when self-pollinated or when crossed with another true-breeding organism for the same traits

hybrid the offspring of two different true-breeding plants

Some garden peas are **true-breeding** plants. This means that, when self-pollinated or crossed with a similar true-breeding plant, they will always produce offspring that have the same trait. For example, if a true-breeding pea plant with purple flowers is self-pollinated, or crossed with another true-breeding plant with purple flowers, all offspring plants will have purple flowers. The offspring of two different true breeding plants is called a **hybrid**. By preventing pea plants from self-pollinating, Mendel was able to cross-breed plants with specific traits. Mendel removed the male reproductive organs, the anthers, from the flowers of true-breeding plants. He then pollinated true-breeding plants with pollen from other true-breeding plants (**Figure 2**). Since the parent plants were true breeding but had different traits, the offsprings' traits would represent the hybrid condition.

LEARNING TIP

Characteristic or Trait
Do not confuse the terms "characteristic" and "trait." Traits represent the variation within a characteristic. For example, height is a characteristic, while short and tall are traits; sight is a characteristic, while normal vision, near-sightedness, and far-sightedness are traits.

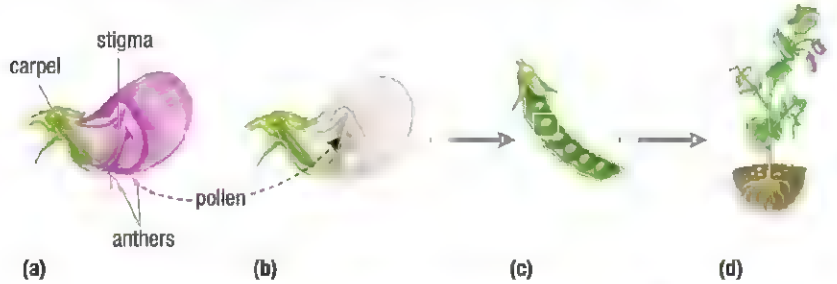


Figure 2 (a) Pollen grains form in the anthers. The egg cell is found in the carpel. (b) Mendel brushed pollen from one plant onto the stigma of a second plant. He had cut the anthers from the second plant so it could not self-pollinate. (c) He then planted the resulting seeds in order to (d) observe the characteristics of the resulting offspring.

Another significant feature of the pea plant is that it has several observable characteristics, each of which is expressed in one of two ways. For example, the shape of the pea may be smooth or wrinkled; the colour of the seeds may be yellow or green. Mendel chose characteristics that always occurred in one of only two ways so that he could distinguish between these traits and thus interpret his data easily.

Mendel performed his experiments on seven hereditary characteristics of the pea plant: flower colour, flower position, stem length, seed shape, seed colour, pod shape, and pod colour (**Table 1**).

Table 1 Characteristics and Traits of Pea Plants

Characteristic	Traits
flower colour	purple/white
flower position	axial (along stems)/terminal (at tips)
stem length	tall/dwarf
seed shape	smooth/wrinkled
seed colour	yellow/green
pod shape	inflated/constricted
pod colour	green/yellow

Mendel's Experiments

In genetics, the breeding of two organisms with different traits is called a **cross**. In order to track the inheritance of a single trait, Mendel crossed true-breeding plants that differed from each other in only one characteristic, such as flower colour. These plants were his parental generation, or **P generation**. The hybrid offspring of the P generation cross were the filial generation, or **F_1 generation** (from the Latin word for son, *filius*). The F_1 generation differed from each other in only one characteristic, making them **monohybrids**. This type of cross, which scientists use to study the inheritance of a single trait from two true-breeding parents, is called a **monohybrid cross**.

Figure 3 shows an example of one of Mendel's monohybrid crosses. Mendel crossed a true-breeding pea plant with purple flowers with a true-breeding pea plant with white flowers. He wondered whether the hybrid F_1 generation would have pink (or "blended") flowers, as some scientists might have predicted. Mendel observed, surprisingly, that all the F_1 plants had purple flowers rather than flowers that were a blend of the two traits in the P generation. It was as though the trait for white flowers had disappeared!

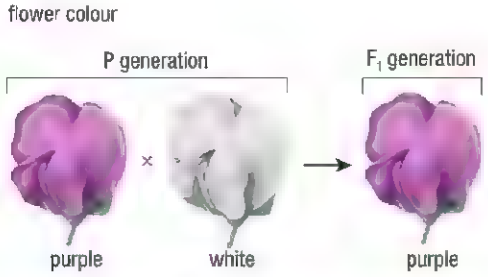


Figure 3 All the offspring of a monohybrid cross between purple true-breeding pea plants and white true-breeding pea plants have purple flowers.

When Mendel allowed the F_1 generation of plants to self-pollinate, the resulting **F_2 generation** consisted of plants with purple flowers and plants with white flowers. This meant that the trait for white flowers had not disappeared but had somehow been masked.

What Mendel did next was fundamentally important in his pursuit of scientific knowledge. He recorded the numbers of the F_2 generation plants according to their traits. He then calculated the ratios of the traits for each characteristic.

Mendel found a pattern. In each F_1 generation, only one of the two traits was present. In the F_2 generation, both traits were present—the missing trait had reappeared. This disproved the "blending" theory. The traits in the F_2 generation were repeatedly expressed in a ratio of approximately 3:1.

Mendel differed from other investigators of heredity at the time in some key ways. He kept detailed records and looked for mathematical patterns in his data. Most importantly, he repeated his experiments more than once, crossing thousands of pea plants in the process. He was aware that in order to obtain reliable results he needed to have a large sample size. He knew for example that the ratio of male to female births could not be determined by looking at just a few families. Mendel's conclusions were drawn from a large volume of documented data. In this respect, Mendel was a pioneer in the development of scientific inquiry.

cross the successful mating of two organisms from distinct genetic lines

P generation the parent plants used in a cross

F_1 generation the offspring of a P-generation cross

monohybrid the offspring of two different true-breeding plants that differ in only one characteristic

monohybrid cross a cross designed to study the inheritance of only one trait

F_2 generation offspring of an F_1-generation cross

The results of Mendel's careful analysis are summarized in **Figure 4**.

Characteristics	P	F_1	F_2		Ratio
seed shape	round × wrinkled	all round	5474 round	1850 wrinkled	2.96 : 1
seed colour	yellow × green	all yellow	6022 yellow	2001 green	3.01 : 1
pod shape	inflated × constricted	all inflated	882 inflated	299 constricted	2.95 : 1
pod colour	green × yellow	all green	428 green	152 yellow	2.82 : 1
flower colour	purple × white	all purple	705 purple	224 white	3.15 : 1
flower position	axial × terminal	all axial	651 axial	207 terminal	3.14 : 1
stem length	tall × dwarf	all tall	787 tall	277 dwarf	2.84 : 1

Figure 4 Mendel's crosses with seven different characteristics in peas, including his results and the calculated ratios of the offspring

Mendel's Conclusions: The First Law of Mendelian Inheritance

Mendel concluded that traits must be passed on by discrete heredity units, which he called factors. Although these factors might not be expressed in an individual, they can still be passed on. Mendel called the factor that was expressed in all the F_1 generations the "dominant factor." The factor that remained hidden but was expressed in the F_2 generation is the "recessive factor." In addition, once Mendel had compiled all the data and realized that there was a definite pattern, he recognized that the 3:1 ratio was an important clue. Why would a trait present in the P generation *not* be expressed in the offspring (F_1) but then reappear in 25 % of the second generation (F_2)? Mendel had noticed a pattern in the data. Now, he had to try to explain it.

law of segregation a scientific law stating that (1) organisms inherit two copies of genes, one from each parent and (2) organisms donate only one copy of each gene to their gametes because the genes separate during gamete formation

Mendel's next two conclusions form the **law of segregation**:

- For each characteristic (such as flower colour), an organism carries two factors (genes): one from each parent.
- Parent organisms donate only one copy of each gene in their gametes. During meiosis, the two copies of each gene separate, or segregate.

Using his data, Mendel was able to predict the results of meiosis long before the discovery of chromosomes. In addition, Mendel recognized that traits are inherited in distinct units and that an organism inherits two copies of each unit—one from each parent. Today, these distinct units are called *genes*, and we know that they are passed on from one generation to the next. Typically, each gene determines a specific characteristic that will appear in the individual, such as seed colour or pod shape.

Alleles: Alternate Forms of a Gene

Recall from Chapter 4 that each gene has a locus, or position, on a chromosome. Most genes exist in at least two forms. Each form of a gene is called an **allele**. Your cells have two alleles for each gene. One allele for the gene is inherited on a chromosome from one parent, and the other allele is inherited on the homologous chromosome from the other parent.

allele a specific form of a gene

Each parent passes on one copy of each chromosome to the offspring via gametes. Gametes are formed during meiosis. During anaphase of meiosis I (Section 4.3, Figure 6), homologous chromosomes separate. This ensures that each gamete receives only one chromosome from the pair and therefore receives only one allele for each gene. Which of the two alleles will be passed on is random and purely a matter of chance

The two alleles that an individual inherits from its parents for a particular characteristic may be the same or they may be different. Different allele combinations can result in different traits for that characteristic. If the two alleles for a particular gene are the same, the individual is **homozygous** for that allele. This would be the case, for example, if both flower-colour alleles coded for white flowers. If, however, one allele coded for white flowers while the other coded for purple flowers, the alleles would be heterozygous. The term **heterozygous** describes an organism that has two different alleles for a gene.

homozygous describes an individual that carries two of the same alleles for a given characteristic

heterozygous describes an individual that carries two different alleles for a given characteristic

The set of alleles that an individual has is its **genotype**. An individual's genotype includes all forms of an individual's genes, even if some of these genes remain "hidden." In contrast, the traits of an individual make up its **phenotype**. The alleles that are expressed determine an individual's phenotype.

genotype the genetic makeup of an individual

phenotype an individual's outward appearance with respect to a specific characteristic

Dominant and Recessive Alleles

In heterozygous individuals, which allele is expressed? As Mendel observed in his experiments, some alleles were expressed while others remained hidden. A **dominant allele** is an allele that expresses its phenotypic effect whenever it is present in the individual. A **recessive allele** is expressed only when both alleles are of the recessive form.

dominant allele the allele that, if present, is always expressed

recessive allele the allele that is expressed only if it is not in the presence of the dominant allele, that is, if the individual is homozygous for the recessive allele

In Mendel's experiments, the allele for purple flowers was dominant over the allele for white flowers. This explains why, when Mendel crossed two true breeding plants with different alleles, all the flowers were the same colour. The resulting F_1 generation expressed only one allele.

Geneticists use letters to represent alleles. Uppercase letters represent dominant alleles; lowercase letters represent recessive alleles. An individual's genotype is expressed with one letter for each allele. As an example, the gene for plant height results in tall plants or dwarf (short) plants. The allele for tall plants is dominant and represented by an uppercase *T*. The allele for dwarf plants is recessive and assigned a lowercase *t*. Possible genotypes for the plant are homozygous dominant (*TT*), homozygous recessive (*tt*), or heterozygous (*Tt*). However, there are only two possible phenotypes: tall and short (**Figure 5**).

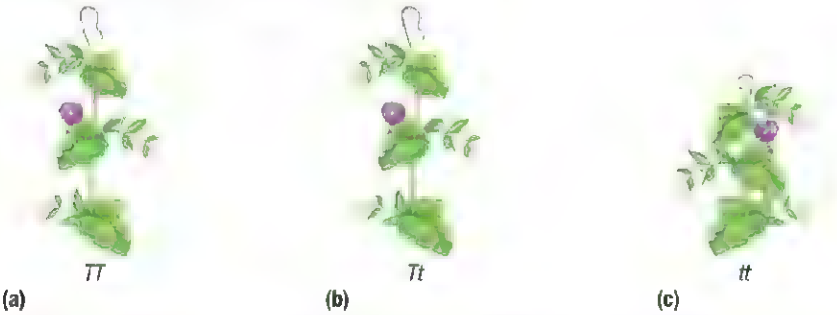


Figure 5 (a) Homozygous dominant plants inherit two *T* alleles, and are tall. (b) Heterozygous plants inherit one *T* allele and one *t* allele, and are tall. (c) Homozygous recessive plants inherit two *t* alleles, and are short.

INFLUENCE OF ALLELES ON PHENOTYPE

It is not possible to determine whether the genotype of a tall pea plant is *TT* or *Tt* just by looking at it. Why do two different genotypes result in the same phenotype? Whenever an individual has at least one copy of the dominant allele, that allele is expressed. All tall plants are either *TT* or *Tt*. It is the *T* allele that makes them tall. Only plants that have no *T* allele—only *tt* plants—show the dwarf phenotype. In heterozygous plants, only the *T* allele is expressed.

What makes an allele dominant or recessive? One common situation occurs when the dominant allele codes for a working protein, while the recessive allele does not. For example, melanin is a pigment responsible for colour in our eyes, skin, and hair. Humans have two forms of the gene for the production of melanin. One form of the gene—call it allele *M*—provides instructions for the production of melanin. The other form—allele *m*—is unable to code for the production of melanin. Only a single copy of the *M* allele (like a single set of instructions) is needed to produce melanin. Individuals who produce melanin have normal eye, skin, and hair colour. An *Mm* individual can make melanin just as easily as an *MM* individual, but *mm* individuals are unable to produce melanin. These individuals have the condition known as albinism (**Figure 6**). In this case the *M* allele is said to be dominant over the *m* allele, because the normal colour phenotype is expressed whenever an *M* allele is present, and the albino phenotype is expressed only in *mm* individuals.

You will learn more about the relationships between alleles and their resulting phenotypes in Section 5.2.

LEARNING TIP

Dominance

In genetics, dominance refers only to which gene is expressed in an organism. It does not mean that the allele is stronger, better, or more common than the recessive allele.

Figure 6 People with albinism lack melanin and are extremely susceptible to sun damage.

Predicting the Inheritance of Alleles

Geneticists use monohybrid crosses to study inheritance. They cross two true-breeding parents that differ in a single trait. In other words, the study involves the inheritance of two alleles for a single characteristic. Mendel's experiments consisted of many crosses. As a result of these experiments, he developed a way of mathematically predicting the proportions of phenotypes in the offspring. Biologists now use Punnett squares to copy Mendel's analysis. A **Punnett square** is a diagram used to predict the proportions of genotypes in the offspring resulting from a cross between two individuals (**Figure 7**).

Punnett square a diagram that summarizes every possible combination of each allele from each parent; a tool for determining the probability of a single offspring having a particular genotype

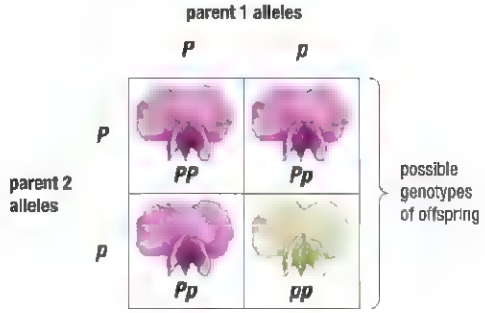


Figure 7 A Punnett square is a grid system for predicting the possible genotypes of offspring

probability the likelihood that an outcome will occur if it is a matter of chance

Probability is a measure of the chance that an event will happen. For example, when you flip a coin, there is a 50 % chance (50:50) that the coin will land on the side you have selected. However, this does not mean that if you flip the coin 10 times you will get heads 5 times and tails 5 times. Each flip of the coin is an independent event.

Punnett squares are valuable mathematical tools for geneticists. Punnett squares are used to predict the probability of different genotypes and phenotypes that may result from a given cross. In addition, they are a graphic summary of every possible combination of maternal and paternal alleles. In the following tutorial, you will learn how to set up Punnett squares, execute crosses, and interpret the results.

Tutorial 1 Predicting Single-Characteristic Inheritance

Sample Problem 1: Homozygous Dominant/Homozygous Recessive Cross

In pea plants, the allele for yellow seed colour, *Y*, is dominant over that for green seed colour, *y*. Consider a cross between a pea plant that is homozygous for yellow seeds and a plant that is homozygous for green seeds. Create a Punnett square to determine the possible genotypes and phenotypes of the offspring.

Solution

The plant that is homozygous for yellow seed colour has a genotype of *YY*. The plant that is homozygous for green seed colour has a genotype of *yy*.

Step 1. Draw a Punnett square that shows the genotypes of the two parents and the gametes that they can produce.

Write the symbols for the gametes across the top and along the left side of the square (**Figure 8**). Note that each parent can supply two possible gametes, each containing one of two possible alleles.

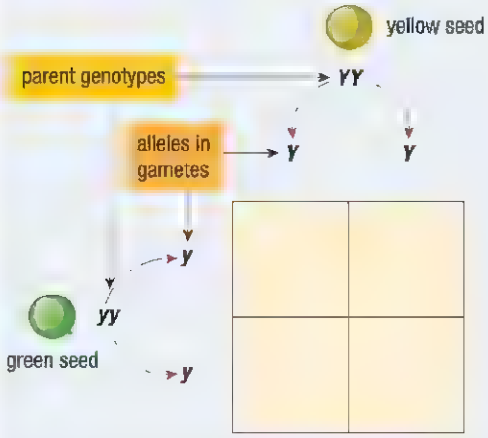


Figure 8 An incomplete Punnett square showing the possible gametes from each parent

Step 2. Fill in the boxes of the Punnett square by combining the gametes corresponding to each row and column.

Each box represents a possible offspring genotype (**Figure 9**).

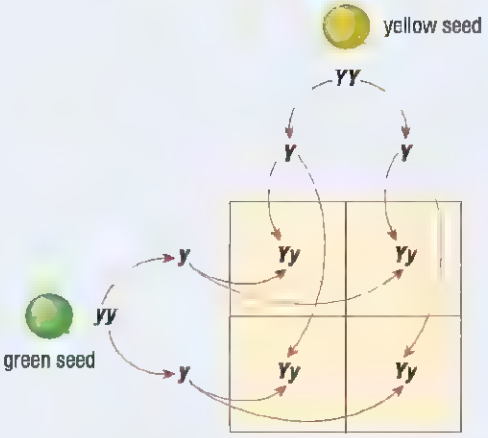


Figure 9 A complete Punnett square showing all the possible genotypes for the offspring.

The four possible genotypes for the cross between a pea plant that is homozygous for yellow seed colour and a pea plant that is homozygous recessive for green seed colour are *Yy*, *Yy*, *Yy*, and *Yy*. The offspring will all have the genotype *Yy*, so all will have the yellow seed phenotype.

Sample Problem 2: Heterozygous/Heterozygous Cross

Two heterozygous yellow seed plants (*Yy*) are crossed. Determine the genotype and phenotype ratios of the F_2 generation offspring.

Solution

Draw a Punnett square and label the parent genotypes. Insert the possible gametes from each parent across the top and down the left-hand side. In this case the two possible gametes from each parent are *Y* and *y*. Proceed to form all the possible offspring.

In the completed Punnett square, there are 1 *YY*, 2 *Yy*, and 1 *yy* genotypes (**Figure 10**). Therefore, the genotype ratio is 1 homozygous dominant plant (*YY*) to 2 heterozygous plants (*Yy*) to 1 homozygous recessive plant (*yy*), or 1:2:1. Both *YY* and *Yy* plants have yellow seeds. The phenotype ratio in the F_2 generation is 3 yellow seed plants (1 *YY* + 2 *Yy*) to 1 green seed plant (1 *yy*) or 3:1.

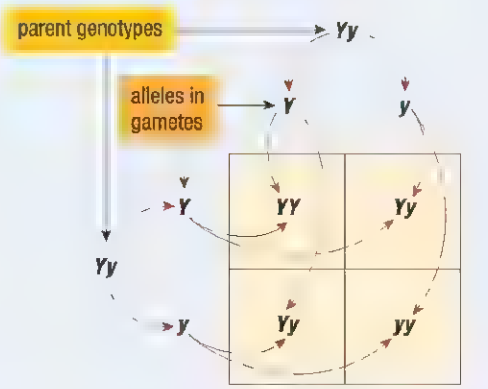


Figure 10

Sample Problem 3: Determining Parent Genotype Using Offspring Phenotype Ratios

In one cross of tomato plants, 1821 red tomato plants and 615 yellow tomato plants were produced. Determine the probable genotype of the parents. Which allele is dominant? Assume that the trait is influenced by only two alleles and follows the laws of Mendelian inheritance. Use the letters *R* and *r* to represent the alleles.

Step 1. Determine the whole number ratio of red tomato plants to yellow tomato plants.

$$\frac{\text{red}}{\text{yellow}} = \frac{1821}{615}$$

$$= \frac{2.97}{1}, \text{ or approximately } 3:1$$

Step 2. Since this is a 3:1 phenotype ratio, it matches a cross between two heterozygous parents.

Therefore, we predict that red (*R*) is dominant to yellow (*r*), and the parent plants were both *Rr*.

Check Your Answer: Draw a Punnett square to show the cross between two heterozygous red tomato plants (**Figure 11**).

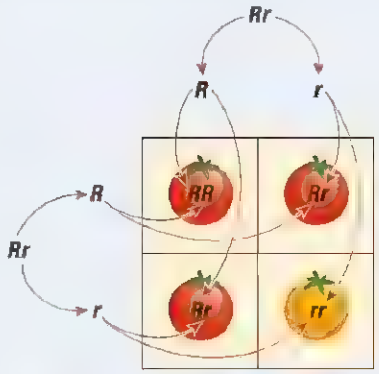


Figure 11

The cross between two heterozygous red tomato plants produces a 3:1 phenotype ratio of red to yellow tomato plants. Genotypically, one tomato plant is homozygous dominant (*RR*), two are heterozygous (*Rr*), and one is homozygous recessive (*rr*). In this case many heterozygous tomato plants were crossed, and of 2436 (1821 + 615) tomato plants, about 1821 out of 2436 (about $\frac{3}{4}$) produced red tomatoes and 615 out of 2436 (about $\frac{1}{4}$) produced yellow tomatoes.

Practice

1. A researcher crossed a homozygous yellow seed plant (*YY*) and a heterozygous yellow seed plant (*Yy*). Determine the genotype and phenotype ratios of the offspring.
2. A researcher crossed a heterozygous yellow seed plant (*Yy*) and a recessive green seed plant (*yy*). Determine the genotype and phenotype ratios of the offspring.

test cross a cross used to determine the genotype of an individual expressing a dominant trait

Test Crosses

A **test cross** is used to determine if an individual exhibiting a dominant trait is homozygous or heterozygous for that trait. A test cross is always performed between the unknown genotype and a homozygous recessive genotype. This is done by crossing the individual with the dominant trait with an individual that exhibits the recessive trait. The results reveal the genotype of the parent:

- If all the offspring display the dominant phenotype, then the individual in question is homozygous dominant.
- If the offspring displays both dominant and recessive phenotypes, then the individual is heterozygous.

Test crosses work well with species that reproduce quickly and in large numbers. For example, test crosses can be used on mice because they produce large litters (7 to 12 mice on average) and have a gestation period of only 18 to 21 days. Also, mice can become pregnant again while nursing a litter. Therefore, a large sample size of mice can be studied in a short period of time. Cows, on the other hand, give birth to only one calf each year and the gestation period of a cow is nine months. This makes test-crossing cows difficult. Although farmers often attempt to breed cows with beneficial traits, it takes a long time to improve a herd.

Today, test crosses are rarely performed. Advances in molecular biology techniques allow geneticists to test for specific alleles within the genotype of an organism directly, rather than having to wait for the production of offspring.

Tutorial 2 Determining an Unknown

Sample Problem 1: Performing a Test Cross

Animal and plant breeders are often interested in whether or not an individual will consistently produce offspring with a desired trait. A breed of rooster has a dominant trait (*S*)—a comb that resembles a series of fingers—while a breed with a recessive trait (*s*) has a flat comb (**Figure 12**).

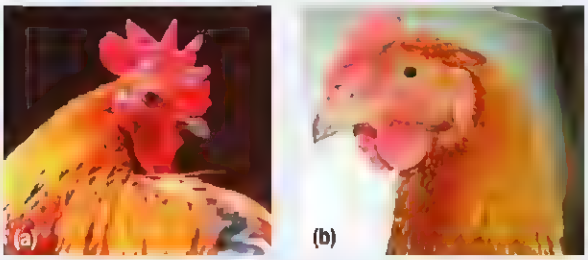


Figure 12 A rooster could have (a) a five-fingered comb or (b) a flat comb

A breeder would like to use a true-breeding, homozygous, five-fingered-comb rooster as a stud in her breeding program. She has many roosters to choose from but does not know if they are heterozygous (*Ss*) or homozygous dominant (*SS*) for the trait.

(a) What type of hen should she cross with the roosters to determine whether a particular rooster is homozygous or heterozygous for the five-fingered comb? Explain your reasoning using Punnett squares.

(b) What are the expected results?

Solution

Step 1. List the possible genotypes of roosters and hens.

The roosters of interest all exhibit the dominant trait, so they must be either homozygous dominant (*SS*) or heterozygous (*Ss*).

There are three possible hen genotypes: homozygous dominant (*SS*), heterozygous (Ss), and homozygous recessive (*ss*).

Step 2. Decide which hen genotype could be used to distinguish homozygous roosters from heterozygous roosters.

No matter which genotype hen is crossed with a homozygous dominant rooster (*SS*), all the offspring will inherit an *S* allele from the rooster and have a five-fingered comb. However, the heterozygous roosters could pass on either an *S* or an *s* allele. Therefore, you can tell them apart if you can detect this *s* allele in the offspring. The only way to tell if an offspring receives an *s* from the rooster is if the offspring also receives an *s* from the hen and is born with a flat comb. Therefore, to ensure that all the offspring receive an *s* allele from the hen, the breeder should choose a homozygous recessive (*ss*) hen.

Step 3. Draw the Punnett squares to determine the expected results (**Figure 13**).

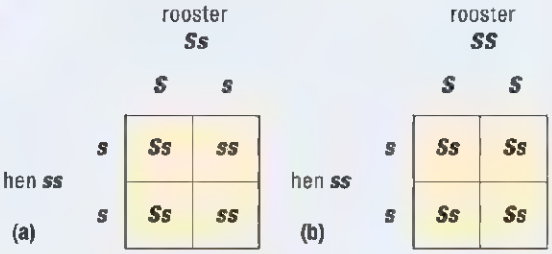


Figure 13 (a) Homozygous recessive hen and homozygous dominant rooster cross, and (b) homozygous recessive hen and heterozygous rooster cross

Answers:

(a) The breeder should cross the rooster with a hen with a flat comb. Using a homozygous recessive (*ss*) hen ensures that all the eggs will contain a recessive allele from the hen and none will contain a dominant *S* allele that would mask the presence of a recessive *s* allele in the rooster.

(b) If the rooster is homozygous dominant, all the offspring will express the five-fingered comb. If the rooster is heterozygous, we would expect that 50 % of the offspring will have a five-fingered comb while the remaining 50 % will have a flat comb.

Practice

1. The gene for whisker length in seals occurs in two different alleles. The dominant allele (*W*) codes for long whiskers, and the recessive allele (*w*) codes for short whiskers.
   (a) If one parent is heterozygous long-whiskered and the other parent is short-whiskered, what percentage of offspring would you expect to have short whiskers? [ans: 50 %]
   (b) A male long-whiskered seal is mated in captivity with a number of different females. With some females all their offspring are long-whiskered, and with some females there are both long- and short-whiskered offspring.
      (i) What is the genotype of the male? How can you be sure? [ans: *Ww*]
      (ii) Would it be possible to find a female mate that would produce only short-whiskered offspring? Explain.
2. Mendel found that crossing wrinkle-seeded (*rr*) plants with homozygous round-seeded (*RR*) plants produced only round-seeded plants. What genotype ratio and phenotype ratio can be expected from a cross between a wrinkle-seeded plant and a heterozygous plant for this characteristic? [ans: 50:50 Rr to rr; 50:50 round seeded to wrinkle seeded]

Mini Investigation

What Are the Chances?

Skills: Performing, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1, A6.3

When two heterozygous individuals are crossed, the probability of producing each genotype is 25 % homozygous dominant, 50 % heterozygous, and 25 % homozygous recessive. In this investigation you will model a cross between two heterozygous individuals. You will then determine the genotype and phenotype ratios of your model F_1 generation. In addition, you will investigate the role that sample size and probability play in producing a 25:50:25 ratio in the F_1 generation.

Equipment and Materials: two small pouches containing 40 beads each (20 white beads and 20 red beads)

1. Assign the red bead the dominant allele, *R*, and the white bead the recessive allele, *r*. Label the two pouches "P_1" and "P_2." Each pouch therefore contains beads that represent the gametes from one heterozygous individual (20 *R* and 20 *r*). Together, the two pouches represent the parent generation.
2. Without looking, draw one bead from pouch P_1 and one bead from pouch P_2. Place the beads together on a flat surface. This represents the joining of two gametes to form a new individual. The colours represent the alleles and the resulting genotype of the offspring. For example, two red beads would represent a new *RR* member of the F_1 generation. Return each bead to the pouch that you drew it from.
3. Repeat Step 2 another 19 times, producing a total of 20 offspring. Record the genotype of each offspring and then tally the total number of homozygous dominant, heterozygous, and homozygous recessive individuals produced.
4. Pool your data with your classmates' data.

A. What was your ratio of homozygous dominant to heterozygous to homozygous recessive individuals in your 20 F_1 offspring? Calculate each percentage by dividing your genotype counts by the total sample size (20) and multiplying by 100. For example, if you had 4 homozygous dominant individuals, the percentage of homozygous individuals would be $\frac{4}{20} \times 100 = 20\ \%$. T/I

B. Did your ratio approach a 25:50:25 ratio? T/I

C. Answer A and B with the pooled class data. Remember to use the total class sample size to calculate percentage values. T/I

D. Check with other students. Were the percentages using the pooled data closer to or farther from the theoretical value than the percentages using single-student data? Why is sample size important? T/I

E. What aspect of Mendel's own experimental design suggests he understood the effects of sample size? T/I A

5.1 Summary

- Gregor Mendel studied heredity in pea plants. He was the first person to successfully record and quantify heredity data.
- Genes have alternate forms known as alleles. Individuals have two alleles for each gene.
- The two alleles are found at specific matching locations on homologous chromosomes.
- Each parent passes on to its offspring only one of its two alleles for each gene. This is called the law of segregation.
- Some alleles are dominant, while others are recessive. Dominant alleles are always expressed in the phenotype, but recessive alleles do not show up unless they are the only type of allele present in the genotype.
- A Punnett square is a tool that can be used to illustrate how alleles are distributed from parent to offspring and to predict the frequency of phenotypes and genotypes within a set of offspring.

5.1 Questions

1. Why was the pea plant an excellent choice for Mendel's inquiry into heredity? K/U
2. Why was it important that Mendel experimented with true-breeding plants? K/U
3. What were the phenotype and genotype ratios of Mendel's F_1 crosses? What do these numbers represent? K/U
4. List Mendel's conclusions from his experiments. How do the conclusions relate to what is known today in the field of genetics? K/U A
5. Differentiate between the following: K/U
   (a) dominant and recessive
   (b) gene and allele
   (c) homozygous and heterozygous
6. State the law of segregation. How does the law relate to meiosis? A
7. Explain why it is important that Mendel had a large sample size of offspring to count in his experiments. T/I
8. The round pea seed allele (*R*) is dominant, while the wrinkled pea seed allele (*r*) is recessive. A heterozygous, round-seeded pea plant is crossed with a wrinkle-seeded pea plant. Use a Punnett square to solve the following: T/I C
   (a) Determine the predicted genotype ratio of the offspring.
   (b) Determine the predicted phenotype ratio of the offspring.
   (c) If this cross produced 50 plants, how many plants would you predict would be wrinkle-seeded pea plants?
9. Humans who have an abnormally high level of cholesterol are said to suffer from familial hypercholesterolemia. The gene for this disorder is dominant (*C*). A man who is heterozygous for familial hypercholesterolemia marries a woman who is homozygous for the recessive allele. What is the probability that they will have children that suffer from this disorder? T/I C
10. Holstein dairy cattle normally have black and white spotted coats. On occasion calves with recessive red and white spotted coats are born (**Figure 14**). A dairy farmer purchases a prized black and white spotted bull. To the farmer's dismay the bull produces a red and white spotted calf when mated to one of his cows.
    (a) What is the genotype of the bull? (Use *R* and *r* for the colour alleles.) T/I C
    (b) What phenotype ratio is expected in the offspring if the bull is mated to a red and white spotted cow?

Figure 14

11. At one time, if a farmer wanted to improve his or her cattle herd, he or she would have to buy an expensive bull from another farmer who had a herd proven to show desirable characteristics. Now, semen from bulls with desirable characteristics can be shipped all over the world to help farmers improve their herds. Use the Internet to learn more about the use of artificial insemination (AI) as a cattle-breeding option. K/U T/I A
    (a) What are the primary advantages and disadvantages of using AI to breed cattle?
    (b) How popular is AI as a breeding method for the beef and dairy industry?
12. Plants contain many hormones that determine their characteristics. Mendel was unaware of the hormones that resulted in the different traits in his plants. T/I A
    (a) Using the Internet or other sources, research the role that the hormone gibberellin plays in determining stem length (plant height).
    (b) How could knowledge of gibberellin release in plants help agriculturists?

GO TO NELSON SCIENCE

5.2 Variations in Heredity

complete dominance a situation where an allele will determine the phenotype, regardless of the presence of another allele

Mendel's experimental work involved the crossing of what he called "typical" plants (homozygous dominant) with "atypical" plants (homozygous recessive). Mendel had discovered **complete dominance**, in which only one of the alleles is expressed, despite the presence of the other allele.

Not all traits are passed on from parent to offspring in the simple patterns that Mendel proposed. Variations in the patterns of heredity exist, and dominance is not always complete.

Incomplete Dominance and Codominance

LEARNING TIP

Notation of Alleles

Notation of alleles for a specific gene can be represented using superscripts. For example, consider the alleles for colour in snapdragons shown in Figure 1. The gene is *C* for colour. The alleles are red (*R*) and white (*W*). When you combine the notations for genes and alleles, the result is C^R for the red allele and C^w for the white allele.

incomplete dominance a situation where neither allele dominates the other and both have an influence on the individual; results in partial expression of both traits

Mendel's work provided an explanation of why the traits of parents did not blend in the offspring. Yet blended inheritance is common in nature. In snapdragons one of the genes that controls flower colour (*C*) has one allele for red (C^R) and one allele for white (C^W). A homozygous C^RC^R plant will produce red flowers, while a homozygous C^WC^W plant will produce white flowers. However, the heterozygous plants will produce pink flowers (C^RC^W). In this case, the actual flower colour (phenotype) is a result of varying amounts of red and white pigments. The homozygous (C^RC^R) plant produces red pigment, the homozygous (C^WC^W) plant produces white pigment, and the heterozygous (C^RC^W) plant produces both red pigment and white pigment. Neither of the alleles is dominant, because the red pigment cannot mask the white pigment and the white pigment cannot mask the red pigment. This type of interaction, in which a heterozygous phenotype is a blend of the two homozygous phenotypes, is known as **incomplete dominance**. Interestingly, in this case, incomplete dominance still results in the same Mendelian genotype ratio of 1:2:1 (**Figure 1**).

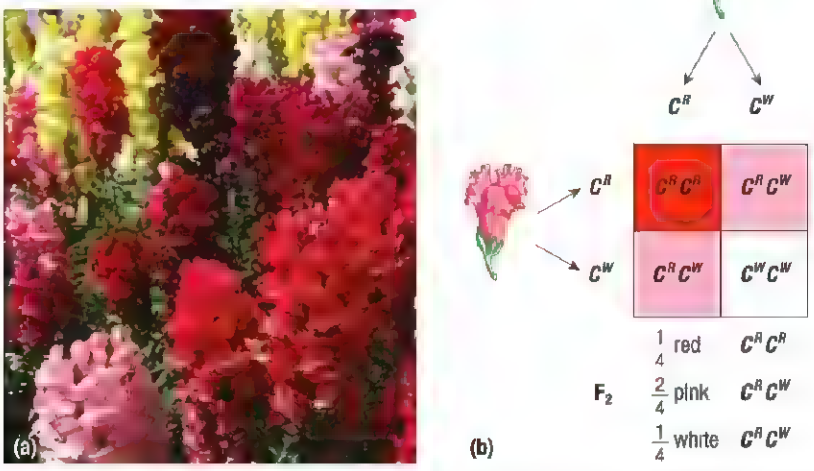


Figure 1 (a) Colour in snapdragons is an example of incomplete dominance. (b) When crossed, red-flowering and white-flowering snapdragons produce pink-flowering offspring. A cross between these pink F_1 individuals produces an F_2 generation with a ratio of 1 red to 2 pink to 1 white (1:2:1).

In the F_1 generation there is only a single phenotype with equal numbers of C^R and C^W alleles. Notice that in the F_2 generation there are now three different phenotypes but the total numbers of C^R and C^W alleles remain equal.

Another type of interaction between alleles occurs when both allele products appear in the offspring at the same time. In this case, a mixed phenotype is generated. This type of interaction is called **codominance**. A classic example of codominance appears in shorthorn cattle. A red bull crossed with a white cow will produce a roan calf (**Figure 2**). Roan calves have intermingled pure white and pure red hair.

codominance a situation where both alleles are expressed fully to produce offspring with a third phenotype

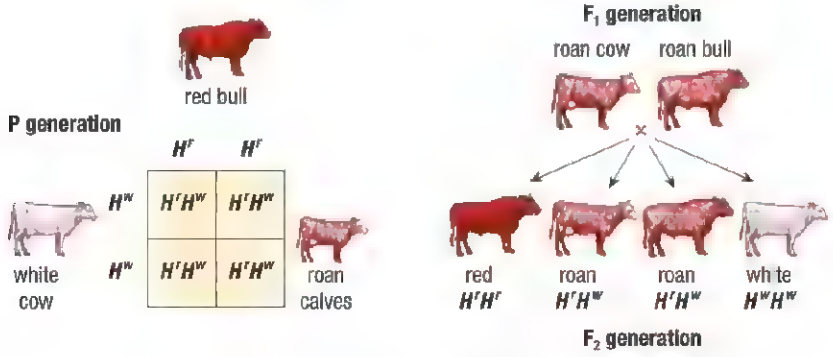


Figure 2 In codominance, one allele does not mask the other allele. Both alleles influence the final phenotype. In shorthorn cattle, roan calves have intermingled red and white hair.

Codominance and Dominance: ABO Blood Types

Human blood type is both a codominant and dominant genetic trait. There are four major blood types: A, B, AB, and O. The blood type gene has three possible alleles. They are I^A, I^B, and i. Each allele codes for a different enzyme that places different types of sugars on the surface of a red blood cell. If you are I^AI^A (type A), an enzyme places one type of sugar on the surface of the cell. If you are I^BI^B (type B), another enzyme places a different sugar on the cell surface. If you are $I^A I^B$ (type AB), both sugars are placed on the cell surface. Type AB blood is an example of codominance. The allele i codes for an enzyme that makes a simpler surface molecule that lacks the extra sugars of the A, B, or AB blood types. If an individual is ii, he has type O blood. If i is paired with I^A or I^B, then the individual expresses the dominant allele (I^A or I^B) and is either type A or type B. Type I^Ai blood and type I^Bi blood are examples of dominant inheritance. **Table 1** shows the distribution and expression of the blood type alleles. One of the gametes is provided by the father and the other is provided by the mother.

Because different blood types exist, it is important that individuals who receive blood transfusions receive blood that is compatible with their own. For example, an individual with type A blood produces an immune response against type B and type AB blood. An individual with type B blood produces an immune response against type A blood and type AB blood. If an incompatible blood type is transfused, the patient's life may be put at risk. In an emergency situation when there is no time to test the patient's blood type, or if a certain blood type is in short supply, type O blood may be used (**Figure 3**). Type O blood is known as the "universal donor." Type AB blood is the "universal recipient."

Table 1 The Distribution and Expression of the Blood Type Alleles

Genotype	Blood type	Able to receive blood from
I^AI^A	A	A, O
I^Ai	A	A, O
I^BI^B	B	B, O
I^Bi	B	B, O
I^AI^B	AB	A, B, AB, O
ii	O	O

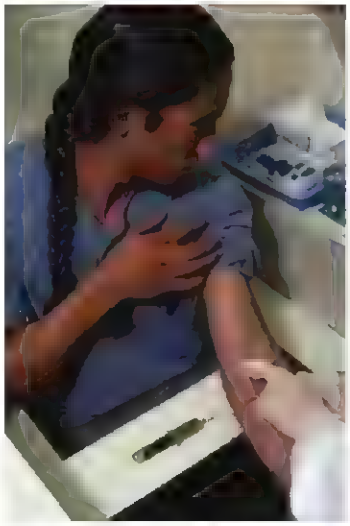


Figure 3 Blood banks are always in need of blood donations. Type O blood is valuable because it is compatible with all blood types

CAREER LINK

Phlebotomist

Phlebotomists are technicians who are specially trained and are certified to draw blood. To learn more about a career in phlebotomy,

GO TO NELSON SCIENCE

The frequency of the blood type alleles varies throughout the world. Genetically isolated populations sometimes have very high frequencies for particular alleles. For example, about 80 % of the Native Americans of the Blackfeet Nation Pikuni Indians in Montana have type A blood because the frequency of the I^A allele is very high in this population.

Codominance can provide an even greater variation in the population: there are genes that have many more alleles than just three or four. For example, the gene that helps determine the acceptance or rejection of a transplant has more than 200 different types of alleles.

WEB LINK

To learn more about blood types,

GO TO NELSON SCIENCE

Investigation 5.2.1

Gummy Bear Genetics (page 215)
You can now complete Investigation 5.2.1.

In this observational study you will use the type and number of "offspring" you have to predict the possible genotypes of the parents. Before starting, review the different Mendelian monohybrid crosses.

5.2 Summary

- Alleles that determine the phenotype regardless of the presence of other alleles follow a pattern of inheritance called complete dominance.
- A heterozygous individual with an intermediate phenotype between the phenotypes of the two homozygous individuals follows a pattern of inheritance called incomplete dominance.
- Codominance occurs when both alleles are fully expressed. Type AB blood is an example of codominance.
- Blood type is an example of a gene with multiple alleles. The three blood type alleles are I^A, I^B, and i. Different combinations of the three alleles produce type A, type B, type AB, and type O blood.

5.2 Questions

1. Explain in your own words the meaning of dominance, codominance, and incomplete dominance. K/U
2. In some chickens, the gene for feather colour is controlled by codominance. The allele for black is F^B and the allele for white is F^W. The heterozygous phenotype is known as erminette. T/I A
   (a) What is the genotype for black chickens?
   (b) What is the genotype for white chickens?
   (c) What is the genotype for erminette chickens?
   (d) If two erminette chickens are crossed, what is the probability that they would have a black chick? A white chick?
3. A geneticist notes that crossing a round radish with a long radish produces oval radishes. When oval radishes were crossed with oval radishes, the F_2 generation had these phenotypes: 100 long, 200 oval, and 100 round radishes. Use symbols to explain the results obtained for the F_1 and F_2 generations. T/I C/A
4. How would Mendel's conclusions have differed if he had worked with plants whose alleles were incomplete dominant? K/U T/I
5. Thalassemia is an inherited anemic disorder in humans. Individuals can exhibit major anemia, minor anemia, or neither. Assume only one gene is involved with two alleles in the inheritance of this condition. What type of inheritance is thalassemia governed by? What are the corresponding genotypes to the three scenarios? K/U T/I
6. List the possible genotypes for an individual with type A blood. K/U T/I A
7. Suppose a father of blood type A and a mother of blood type B have a child of type O. What are the possible blood types of the mother and father? K/U T/I A
8. Suppose a father of blood type B and a mother of blood type O have a child of type O. What are the chances that their next child will be blood type O? Type B? Type A? Type AB? K/U T/I A
9. Why is blood type inheritance an example of both codominance and complete dominance? K/U
10. Another characteristic of human blood is the presence or absence of a blood protein called the Rh factor. People with the protein are Rh+ and those without it are Rh−. Use the Internet and other resources to answer the following questions: K/U T/I A
    (a) What are the genotypes of individuals who are Rh− and Rh+? Is this an example of complete dominance, incomplete dominance, or codominance?
    (b) How can the Rh blood type of two parents be of concern during a pregnancy? How can possible harmful complications be avoided?

GO TO NELSON SCIENCE

Pedigrees—Tracking Inheritance

5.3

Thanks to the laws of heredity, revealed by Mendel, scientists can now do genetic analyses of heritable traits. Human genetics follow the same patterns of heredity seen in organisms such as the garden pea. For example, if we know that a child is born with a trait that neither parent has, then we can infer that the trait must not be controlled by a dominant allele and that the child must have inherited two recessive alleles.

Scientists are especially interested in determining the patterns of inheritance of genes that are beneficial or detrimental to human health. For obvious reasons, experimental genetic crosses cannot be conducted on humans. However, we can use what we know about heredity to investigate individuals and track the inheritance of a trait from generation to generation within a family.

Pedigree Charts

The simplest way to visually follow the inheritance of a gene is to construct a family tree known as a pedigree. A **pedigree** is a chart that traces the inheritance of a certain trait among members of a family. It shows the connections between parents and offspring, the sex of individuals in each generation, and the presence or absence of a trait. The chart is composed of symbols that identify sex and relationships between individuals (**Figure 1**).

pedigree a diagram of an individual's ancestors used in human genetics to analyze the Mendelian inheritance of a certain trait; also used for selective breeding of plants and animals

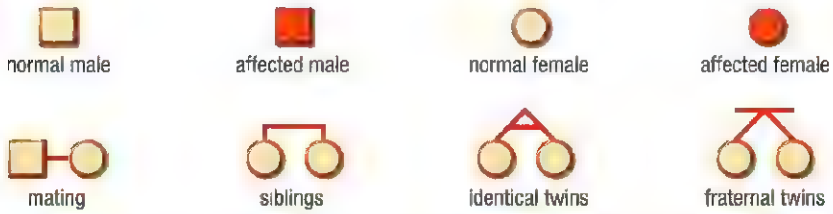


Figure 1 Squares represent males and circles represent females. Individuals who express a trait are shown in a shaded circle or square. Mating between two individuals is shown by a horizontal line, and children are connected to their parents with vertical lines.

Pedigree charts are very ordered within the constraints of the available information about the family. You will notice in **Figure 2** that each generation is identified by Roman numerals and that Arabic numerals symbolize individuals within a given generation. The birth order within each group of offspring is drawn from left to right, from oldest to youngest. Figure 2 shows a pedigree for a family with the trait of freckles

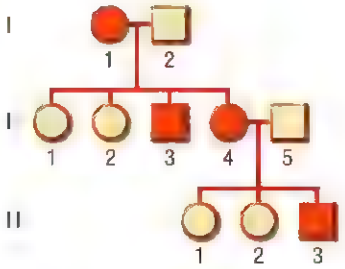


Figure 2 An example of a pedigree chart spanning three generations. In this pedigree, the grandmother (I-1), one of her sons (II-3), one of her daughters (II-4), and her grandson (III-3) have freckles. The allele for freckles (*F*) is dominant over the allele for no freckles (*f*).

Genetic counsellors construct and analyze pedigrees to help trace the genotypes and phenotypes in a family. They can determine if and how any particular trait runs in a family. For example, expectant parents might want to know how a recessive allele for hemophilia (a blood-clotting disorder) has been inherited in past generations. A genetic counsellor can help predict how that gene will be passed on to future generations.

Pedigree charts are also extremely useful for animal and plant breeders. Pedigrees can be used to track the inheritance of both desirable and undesirable traits and in some cases justify very high "stud fees" for prize animals. A farmer, for example, might ask for an opportunity to view a detailed pedigree of a bull before agreeing to pay for breeding with his prize cows. Similarly, a foal born to prize racehorse parents might be sold for millions of dollars based on their pedigrees—and long before its first race

Tutorial 1

Figuring out genotypes from phenotypes on a pedigree chart requires you to use a process of elimination. You can often determine which genotypes are possible and which are not.

Sample Problem 1: Determining Genotypes of Individuals

Marfan syndrome is a genetic disorder that affects the body's connective tissue. When the dominant allele (*M*) is expressed, an individual will have Marfan syndrome. People with no defect in the Marfan allele are homozygous recessive (*mm*). Individuals with the syndrome are typically very tall, with disproportionately long limbs and fingers, and sometimes have problems with their hearts and eyes. Use the pedigree chart (**Figure 3**) to determine the genotypes of all individuals, if possible.

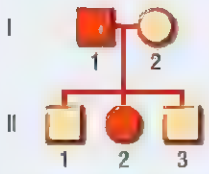


Figure 3 A family's pedigree showing the inheritance of Marfan syndrome

Step 1. Determine which individuals carry a dominant Marfan allele.

The shapes for the father (I-1) and the daughter (II-2) are shaded, indicating that they have Marfan syndrome. The Marfan allele is dominant, so all individuals expressing this trait must be either *MM* or *Mm*. So the father and daughter must be either heterozygous (*Mm*) or homozygous dominant (*MM*). I-1 and II-2 have a dominant allele (*M*) and either another dominant allele (*M*) or a recessive one (*m*) (**Figure 4**).

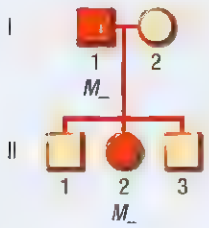


Figure 4

Step 2. Determine which individuals *do not* carry a dominant Marfan allele.

The shapes for the mother (I-2) and the two sons (II-1 and II-3) are not shaded, indicating that they do not have Marfan syndrome. Therefore, they are all homozygous recessive (*mm*) (**Figure 5**).

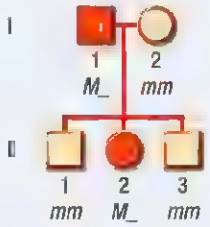


Figure 5

Step 3. Determine which individuals are heterozygous or homozygous for the Marfan allele.

The mother is *mm*, so she can pass on only a normal allele to her offspring. The daughter must be heterozygous (*Mm*). The two sons do not have Marfan syndrome, so they must both have inherited a normal allele (*m*) from the father. The father must be heterozygous (*Mm*). The completed pedigree chart is shown in **Figure 6**.

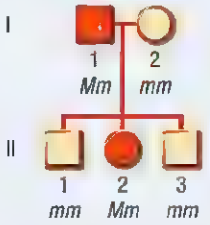


Figure 6 Individuals with Marfan syndrome must have at least one *M*, and recessive individuals must be *mm*.

Sample Problem 2: Determining Modes of Inheritance

Individuals with albinism have a defect in an enzyme that is involved in the production of melanin, a pigment normally found in the skin. These individuals have little or no pigment in their skin, hair, and eyes. The characteristic is governed by only two alleles: the normal allele and the albinism allele. Analyze the pedigree chart at right (**Figure 7**) to determine whether the albinism allele is a dominant or a recessive allele. Then determine the genotypes of each individual. Use *P* and *p* to represent the dominant and recessive alleles, respectively.

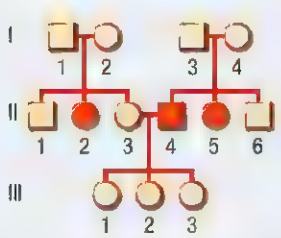


Figure 7 A family's pedigree chart for albinism

Step 1. Determine if albinism is dominant or recessive.

Individuals II-2, II-4, and II-5 have albinism, but none of their parents exhibit this trait. It is not possible to inherit a dominant trait from a parent who is not also dominant. Therefore, the trait must be caused by a recessive allele. The F_1 offspring who have albinism (II-2, II-4, II-5) have inherited two copies of the *p* allele, making them homozygous recessive (*pp*) for the characteristic. The genotypes of II-2, II-4, and II-5 are labelled *pp* (**Figure 8**).

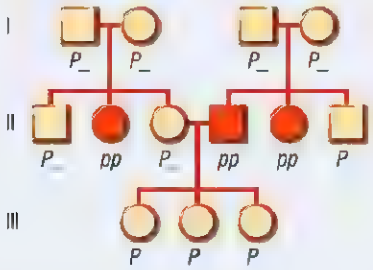


Figure 8 All individuals can be labelled *P* or *pp* based on their expressed traits

Step 2. Determine which individuals carry one copy of the dominant normal allele.

Individuals who do not have albinism must have at least one *P* allele. All dominant individuals are labelled with one *P*, as shown in Figure 8.

Step 3. Determine the genotypes of non-albino individuals.

Every parent of an albino child must have at least one *p* allele. Every albino parent passes on a *p* allele to each of their children. Some but not all of the missing alleles can be filled in by looking at the parents and offspring of recessive ind viduals (**Figure 9**).

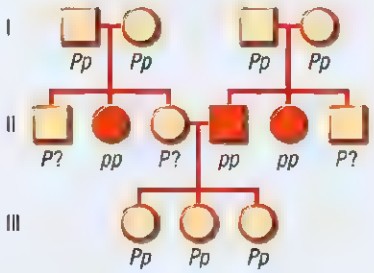


Figure 9 The second allele of *P?* individuals is unknown.

Practice

1. Phenylketonuria (PKU) is a genetic disorder caused by a recessive allele. Individuals with PKU accumulate phenylalanine in their body. High amounts of phenylalanine lead to delayed mental development. **Figure 10** is a pedigree chart that shows the inheritance of the defective PKU allele in one family.
   (a) How many generations are shown in the pedigree chart? [ans: 3]
   (b) Determine the genotypes of the individuals in Figure 10. Let *p* represent the recessive PKU allele.

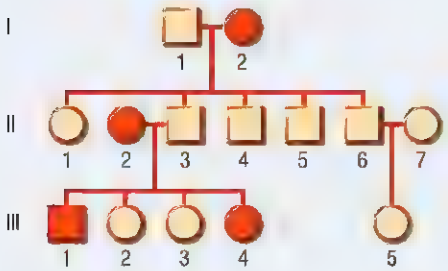


Figure 10

2. Not all humans react strongly to poison ivy. This trait is thought to be controlled by a single a lele. The following pedigree (**Figure 11,** next page) shows the inheritance of sensitivity to poison ivy in one family.
   (a) Analyze the pedigree chart and determine whether the disorder is inherited as a result of a dominant or a recessive trait.

(b) Determine the genotype for each individual if possible.

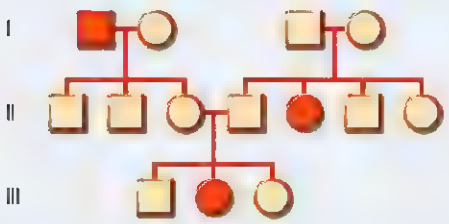


Figure 11 A family's pedigree chart for sensitivity to poison ivy

Sex Linkage—Following the X and Y Chromosomes

Different organisms have different numbers of chromosomes. Humans have 23 pairs of chromosomes. One set of chromosomes consists of the sex chromosomes, while the other 22 sets are autosomes, the non-sex chromosomes. If an allele is found on an autosome, it is said to be under the control of **autosomal inheritance**. With autosomal inheritance, both males and females are affected equally, since there is no difference between the autosomes of males and the autosomes of females.

autosomal inheritance inheritance of alleles located on autosomal (non-sex) chromosomes

However, some alleles that cause genetic disorders are found on the X chromosome. Females (XX) have two copies of the gene, but males (XY), with only one X chromosome, have only a single copy. Since the allele with the disorder is found on the X chromosome and is recessive, this type of inheritance is called **sex-linked** and, more specifically, **X-linked**. If a male inherits the X chromosome from a mother who carries the recessive allele, he will express the disorder because the Y chromosome cannot mask the effects of that allele. The male cannot inherit an X-linked disorder from his father, since a father passes on a Y chromosome to a son. A female must inherit two copies of the recessive gene — one on each X chromosome — in order to express the disorder.

sex-linked describes an allele that is found on one of the sex chromosomes, X or Y, and when passed on to offspring is expressed

X-linked phenotypic expression of an allele that is found on the X chromosome

WEB LINK

Royal Genes
Queen Victoria and her descendants constitute one of the most famous pedigree charts. To explore this pedigree in a case study and learn more about X-linked inheritance,

GO TO NELSON SCIENCE

Some examples of X-linked inheritance are red–green colour blindness, hemophilia A, and male-pattern baldness. Individuals who have hemophilia A are not able to form a clot when they are cut and may bleed for a lengthy period of time. In **Figure 12** the mother is a carrier of the hemophilia allele (X^h), and the father does not have hemophilia. The probability of this couple producing a son who has hemophilia (X^hY) is 25 %, and the probability of their producing a daughter who is a carrier (X^HX^h) is 25 %. There is a 50 % chance that the couple will produce a daughter or son who does not inherit the hemophilia allele (X^HX^H and X^HY).

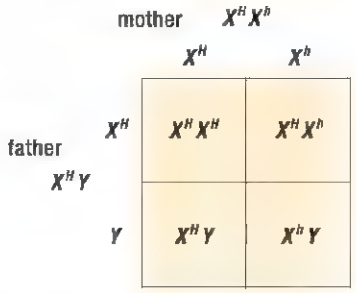


Figure 12 Hemophilia A is X-linked. A female carrier can pass on the hemophilia allele to her sons and daughters. Males cannot pass on hemophilia to their sons.

Y-linked disorders also exist and are passed on from father to son. One reason there are fewer Y-linked disorders than X-linked ones is that the Y chromosome is small and does not carry as much genetic information as the X-chromosome. Reduced fertility in males can be caused by a Y-linked disorder. Males who possess this disorder can have children using medical intervention.

Y-linked phenotypic expression of an allele that is found on the Y chromosome

5.3 Summary

- Pedigree charts are visual representations of a family tree that can be used to follow the inheritance of a trait.
- If an allele is located on an autosome, or a non-sex chromosome, it is transmitted through autosomal inheritance.
- Sex-linked inheritance occurs when a recessive allele is found on the X or Y chromosome and that chromosome is passed on to the offspring.
- In X-linked inheritance, the sexes exhibit different phenotypic ratios. More males than females will express the recessive phenotype, but more females are carriers of the recessive X-linked allele.
- In Y-linked inheritance, traits are controlled by single alleles passed on from fathers to sons on the Y chromosome.

5.3 Questions

1. Sickle-cell anemia is a condition in which the red blood cells of an individual can become shaped like the letter "C." This shape prevents the red blood cells from moving easily through blood vessels. It can result in the cells clumping, blocking blood flow and causing pain, infection, and organ damage. The allele that causes sickle-cell anemia is autosomal recessive (*s*), and the dominant allele can be represented by *S*.
   (a) For the following families, determine the genotypes of the parents and offspring. When it is not possible to decide which genotype an individual is, list both. T/I C
      (i) Two normal parents have four normal children and one with sickle-cell anemia
      (ii) A normal male and a female with sickle-cell anemia have six children, all normal.
      (iii) A normal male and a female with sickle-cell anemia have six children; three are normal, and three have sickle-cell anemia.
   (b) Construct a pedigree chart for the families in (ii) and (iii).
2. Distinguish between autosomal inheritance and sex-linked inheritance. K/U
3. A male with hemophilia (X^hY) mates with a woman who does not carry the hemophiliac gene (X^HX^H). Use a Punnett square to answer (a) and (b). T/I
   (a) What is the probability of producing sons or daughters who have hemophilia?
   (b) What is the probability of producing daughters who are carriers of the hemophiliac allele?
4. Examine the pedigree charts in **Figures 13** and **14**. T/I
   (a) Determine whether the mode of inheritance for the traits is autosomal dominant or autosomal recessive.

Figure 13

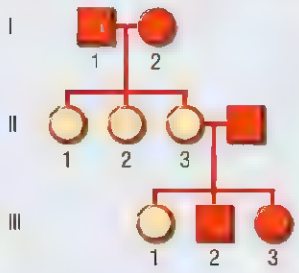


Figure 14

   (b) Copy each pedigree chart. Then label the genotype of each individual in the pedigree chart. Assume that the dominant allele is *A* and the recessive allele is *a*.
5. Hairy ears is a rare condition that is sex linked. Let *H* be the dominant allele (non-hairy ears) and *h* be the recessive allele (hairy ears). T/I
   (a) Examine the pedigree chart in **Figure 15**. Determine if the condition is X-linked or Y-linked.
   (b) Label all possible genotypes.

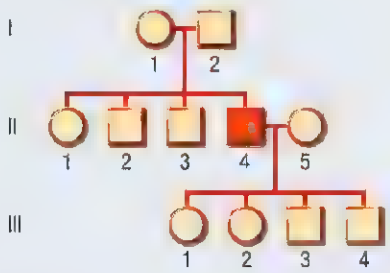


Figure 15

5.4 — *Biology* JOURNAL —

The Gene Hunters

SKILLS HANDBOOK A4

ABSTRACT

The road to scientific achievement is a challenging one that requires scientists to have determination, perseverance, and innovation. This is well illustrated by the history of our studies of Huntington's disease. This deadly genetic disorder strikes people in midlife and does not yet have any effective cure or treatment. Motivated by personal tragedy, and supported by advances in DNA technology, Dr. Nancy Wexler was a pioneer in the hunt for the faulty gene. These efforts not only led to the discovery of the Huntington's disease gene (and many others) but also opened up avenues of future research that offer hope for possible treatments and a cure.

Introduction

Huntington's disease (HD) is a devastating neurological genetic disorder. Inherited as a dominant autosomal trait, this late-onset disease has symptoms that do not usually appear until individuals are between 30 and 50 years of age. Symptoms include uncontrollable movements, intellectual and emotional deterioration, and other health complications that may lead to death.

First described as early as the sixteenth century, the unusual symptoms were thought by some to be evidence of demonic possession. Tragically, ignorance of genetics and such beliefs likely led to the execution of many HD sufferers during the witch trials of the Middle Ages. It was not until 1872 that American physician George Huntington provided the first detailed description of the disease and established it as an inherited disorder.

By the early twentieth century, Mendelian laws of inheritance had become widely accepted in science, and researchers had learned that HD causes parts of the brain to degenerate. Unfortunately, with no understanding of the molecular basis of inheritance, the genetic cause of HD remained a mystery to scientists.

Venezuelan physician Americo Negrette unknowingly made a major contribution to unravelling the mystery. He studied two villages on Lake Maracaibo, Venezuela, that had a very high incidence of a neurological disease known locally as *el mal* (the bad). His findings, published in 1955 in Spanish, went largely unnoticed for more than a decade, until a young researcher discovered them while searching for answers to her own questions.

Personal Motivation

In 1968, at the age of 23, Nancy Wexler became very interested in genetics—her mother had started to show the symptoms of HD. Wexler maternal grandfather and three uncles had already died of the disease. Fighting the disease became the primary focus for Wexler and her family. With great determination, she graduated from university at the top of her class and became a researcher for the National Institutes of Health in the United States.

The Search for Answers

Wexler believed that the first step to finding a treatment or cure for HD would be to discover the gene responsible for the disease. In 1981, after obtaining vital federal funding, she headed to the shores of Lake Maracaibo.

Wexler studied family histories and prepared pedigrees of thousands of individuals in the Lake Maracaibo communities (**Figure 1**). In 1983, using pioneering advances in DNA technology, researchers were able to identify a section of DNA near the tip of chromosome #4 that is a marker for the HD gene. A marker for a genetic disease is a DNA sequence that is associated with a specific gene and is found in the same position on a chromosome in people who have or are predisposed to having that disease. The discovery of this marker meant that, for the first time, there was a conclusive test for people at risk of inheriting the disorder.

Figure 1 Since the early 1980s, Nancy Wexler has compiled a community pedigree of over 18 000 individuals.

INNOVATIONS AND ADVANCES

In 1983, modern genetics and the ability to analyze DNA were still in their infancy. It took the efforts of many scientists more than a decade before the actual gene for HD was identified. The discovery of the HD gene in 1993 was monumental. The gene is abnormally long and prone to repeated mutation events (changes in the DNA code as it replicates). These mutations result in large numbers of copies of a very short portion of the gene. This discovery led to an understanding of an entire family of genetic diseases caused by similar abnormal "repeat sequences" of DNA.

By 1996, advances in genetic technology had enabled scientists to begin conducting research on the HD gene in living organisms. Genetically modified mice were created that contained the actual human HD gene. These "model organisms" could be used to conduct experiments and study the activity of the gene. The mice were also useful for preliminary testing of new drugs without putting human patients at risk.

A number of other scientific and technological innovations have contributed to our understanding of Huntington's disease. Positron emission tomography (PET) scans produce detailed nuclear images of areas of the body. Other technologies are used to monitor and study the progression of the disease in the brain and changes in body chemistry and metabolism. Stem cell research has been conducted in tissue cultures and animal models. Human stem cells containing the HD gene can now be grown and used to study the effect of treatments on the development of the disease directly within human cells (**Figure 2**).

The Challenges Ahead

Even with tremendous strides in understanding, scientists still do not know exactly how the protein produced by the Huntington's gene actually causes cell deterioration and death. There are not yet any truly effective treatments or a cure.

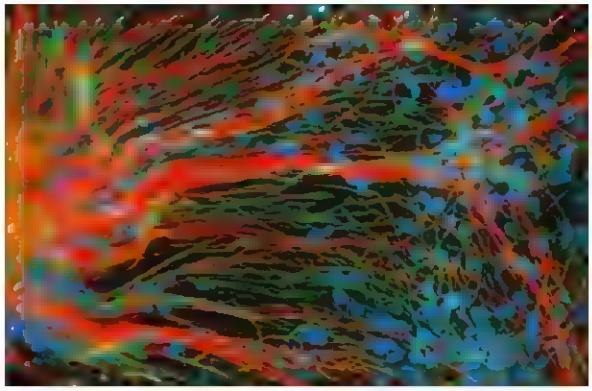


Figure 2 In the future, stem cells may be able to replace cells that have the defective Huntington's gene.

Still, researchers and patients remain hopeful as advances in science continue. Perhaps an effective drug will soon be found. Perhaps some day a patient's own stem cells will be used to regrow and replace defective or lost brain cells. Perhaps some day we will have the ability to actually correct or replace the defective gene using gene therapy.

Meanwhile, the villagers on the shore of Lake Maracaibo, and other people with Huntington's around the world, remain the subject of intense scientific investigation as they continue to suffer from this horrific disease.

Further Reading

Quarrell, O. (2008). *The Facts: Huntington's Disease*. New York, NY: Oxford University Press.

Wexler, A. (2010). *The Woman Who Walked into the Sea*. Ann Arbor, MI: Sheridan Books.

GO TO NELSON SCIENCE

5.4 Questions

1. Prepare a brief chronology of events leading to our current understanding of HD. C
2. Nancy Wexler could not have accomplished her goals on her own. Use examples from this article to describe how the discipline of science builds up a knowledge base over time. A
3. Use the example of Huntington's disease to illustrate how advances in one area of science can be applied to others. A
4. Why would Dr. Nancy Wexler look at family pedigree charts of the people of Lake Maracaibo as a starting point for her search for the Huntington gene? T/I
5. Nancy Wexler has a strong affinity for the villagers of Lake Maracaibo. She said, "The Venezuelan families have given us many gifts. . . . It is important that the world understand how much they have given. It would be fitting if they could be the first to reap the benefits of all future therapies." T/I C
   (a) Use the Internet and other resources to investigate the latest therapies that are being researched for future implementation. Report back on two that you think sound promising.
   (b) Do you agree with Dr. Wexler that the people of Lake Maracaibo should be the first to receive a successful treatment? Why or why not?

GO TO NELSON SCIENCE

5.5 Genetic Disorders

Many human disorders have a genetic component, but the onset of a disorder may vary depending on life conditions. Some disorders can be detected at birth, while others do not manifest themselves until an individual has reached a certain age range. Some disorders can be treated and managed, while others lead to debilitating symptoms and premature death. Research geneticists spend a great deal of time and money to better understand the genetic components of such disorders. Their ultimate goal is to detect, prevent, or fix the genetic component of these disorders.

Figure 1 A child undergoing physical therapy for cystic fibrosis. The child's chest or back is tapped repeatedly to loosen the mucus in the lungs. This makes it easier for the child to rid his body of the mucus.

CAREER **LINK**

Pulmonologist

A pulmonologist is a physician who specializes in respiratory diseases. To learn more about a career in pulmonology,

GO TO NELSON SCIENCE

mutation a change in the genetic code of an allele; the change may have a positive effect, a negative effect, or no effect

carrier testing a genetic test that determines whether an individual is heterozygous for a given gene that results in a genetic disorder

genetic screening tests used to identify the presence of a defective allele that leads to a genetic disorder

Cystic Fibrosis

Cystic fibrosis (CF) is the most common fatal genetic disease in Canada. The life expectancy for individuals with CF is less than 40 years, though this is increasing every year — some individuals with CF have lived into their seventies. The disease causes the body to produce thick, sticky mucus that clogs the lungs, leads to infections, and blocks the release of enzymes from the pancreas. The pancreas produces digestive enzymes that help break down protein, fats, and carbohydrates during digestion, so children and adults who have CF must take a large number of replacement enzymes daily in pill form. In addition, individuals with cystic fibrosis must undergo physical therapy or other treatments every day to help loosen accumulated mucus in the lungs (**Figure 1**).

Cystic fibrosis is the result of a **mutation**, or a change in the genetic code. The first such defective gene was isolated and identified in 1989 by research geneticist Dr. Lap-chee Tsui and his team at the Hospital for Sick Children in Toronto. The mutated copy of the gene is recessive, so a child must inherit both copies of the defective allele from his or her parents in order to express CF. In the past, parents realized that they were carriers only when their child was born with CF.

Today, **carrier testing** is used to identify individuals who carry disorder-causing recessive genes that may be inherited by their children. In fact, the Canadian College of Medical Geneticists recommends that carrier testing for cystic fibrosis be available to anyone who has a family history of CF. Genetic counsellors work with couples that have an increased risk of conceiving a child with CF.

Testing for the presence of the mutated gene in the genome is known as **genetic screening**. Currently, we are aware of approximately 200 mutations that lead to cystic fibrosis. The severity of symptoms depends on which DNA mutation an individual has. The genetic test is based on a blood sample that is sent to a molecular diagnostic laboratory. In Canada the test is able to detect approximately 85 % of CF mutations. **Table 1** shows the probability of conceiving a child with CF according to different test result scenarios.

Table 1 Risk of Having a Child with Cystic Fibrosis before and after Carrier Testing in Canada

Test status of parents	Risk of having a child with CF
No test performed	1 in 2500
Both partners tested: results show one positive, one negative	1 in 600
Both partners tested: results show both positive	1 in 4

Source: Canadian Cystic Fibrosis Foundation, Carrier Testing for Cystic Fibrosis

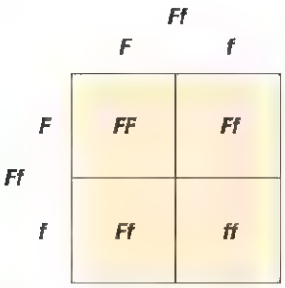


Figure 2 The probability of these two parents conceiving a child who *does not* express cystic fibrosis is 75 %.

From Mendel's Punnett square for a recessive autosomal trait, we know that the probability of two heterozygous parents (*Ff* and *Ff*) conceiving a child with CF (*ff*) is 25 %, a child who is a carrier (*Ff*) is 50 %, and a child who does not carry the mutation (*FF*) is 25 % (**Figure 2**). Therefore, if both parents have tested positive for the mutation, the probability of giving birth to a child with CF is $\frac{1}{4}$, as indicated in Table 1.

Research This

Life with a Genetic Condition

Skills: Researching, Analyzing, Evaluating, Communicating SKILLS HANDBOOK A2.1, A5.1

Cystic fibrosis is a genetic condition that can be managed by a variety of therapies and lifestyles. In the past people with CF barely lived past childhood. Today, with treatment and healthy lifestyle choices, many people with CF live well into adulthood. They can go to school, pursue careers, play sports, and have families. Some individuals with CF even live to be senior citizens. With advances in genetics, it is quite reasonable to think that a child born with CF today may live to see a cure for the disorder.

1. Use the Internet and other resources to find stories about people who have cystic fibrosis.
2. Make a list of strategies that individuals with CF use to manage their condition. Research and record the ways each person's strategy helps him or her, as stated by that individual.

A. What similarities do the strategies share? A

B. Think about how each person's strategies would fit into your daily life, if you had CF. Describe in paragraph form how your daily schedule would change. Do you think some CF strategies could fit easily into your own lifestyle? What changes would you have to make? What would stay the same? C A

GO TO NELSON SCIENCE

Breast Cancer

Not all genetic disorders appear right from the onset of life. As you learned in Section 5.4, Huntington's disease does not usually show up until an individual is at least middle-aged. At this point, the potentially harmful allele may have been passed on to offspring. Cancer genes also fall into this category. Cancer is uncontrolled cell division.

BRCA1 and BRCA2 are human genes that belong to a class of genes known as tumour suppressors. Tumour suppressors produce chemicals that inhibit the growth of tumours in the body. If a woman carries a defective copy of either of these genes, she has an increased chance of developing breast or ovarian cancer at an early age.

Not all breast cancers are caused by a mutation in the BRCA1 or BRCA2 gene. A woman has a 12 % chance of developing breast cancer if she does not carry a copy of one of the defective genes, but a chance of 60 % if she is a carrier of even a single copy of either the defective BRCA1 or BRCA2 genes. The environment plays a significant role in determining whether cancer genes are turned on or off. For example, a woman who is exposed to estrogen-mimicking chemicals found in some lawn pesticides and certain types of plastics has a greater chance of developing breast cancer.

A woman who has a family history of breast cancer may choose to undergo genetic screening for the mutated BRCA1 or BRCA2 gene. If she does have a mutation, she may decide to have a mastectomy, a procedure that involves the removal of part or all of the breast tissue. Alternatively, she may choose to increase surveillance of her breast and ovarian health.

WEB LINK

For more information on estrogen-leaching plastics,

GO TO NELSON SCIENCE

Phenylketonuria

Breast cancer and cystic fibrosis are potentially fatal conditions caused by a mutation in a gene. In contrast, individuals with **phenylketonuria (PKU)** are able to live normal lives with modifications to their lifestyle.

phenylketonuria (PKU) an autosomal, recessive, inherited genetic disorder that results in the accumulation of phenylalanine in the tissues and blood

Phenylketonuria is a genetic disorder in which the affected individual is unable to utilize the amino acid phenylalanine, which the body needs in order to make proteins and essential brain chemicals. In Canada, about 1 in 20 000 people have PKU. Individuals with PKU do not possess the enzyme that breaks down phenylalanine

(found in most foods), and it accumulates in the blood and tissue. The brain function of a child with PKU does not develop normally.

Phenylketonuria is a recessive trait. Both parents must be carriers of the defective allele in order to pass it down to the child. Unlike for cystic fibrosis, researchers have not isolated the phenylketonuria gene. Hence prospective parents cannot be counselled or tested for the probability of producing a PKU child. Instead, every newborn is screened for the presence of PKU.

When a baby is about three days old, a few drops of its blood are tested for elevated amounts of phenylalanine and other compounds that are associated with genetic disorders. If the test is positive, more tests are performed to confirm or rule out PKU. If the infant does suffer from PKU, he or she must follow a diet that severely limits intake of high-protein foods such as meat, fish, eggs, and milk. If the diet is followed, the child will be able to lead a normal life. If PKU is left untreated, the child will suffer arrested mental development, decreased body growth, and poor development of tooth enamel.

Other Disorders

Table 2 summarizes some common genetic disorders. Researchers are hunting for the genetic mutations that cause these disorders and developing tests to screen for them.

Table 2 Genetic Disorders and Their Mechanism of Inheritance

Disorder	Adverse health effects	Mechanism of inheritance
alkaptonuria the accumulation of alkapton in the body	kidney stones, damage to cartilage	recessive allele
cystic fibrosis causes the body to produce thick, sticky mucus that clogs the lungs and pancreatic duct	infections; blocks the release of enzymes from the pancreas	recessive allele
galactosemia the inability to digest galactose	infants experience jaundice, failure to thrive, vomiting, and diarrhea; may lead to death if undiagnosed	recessive allele
hemophilia body cannot form blood clots	excessive bleeding	recessive allele
Lesch–Nyhan syndrome buildup of uric acid in the body	gout, kidney problems, self-injuring behaviour	recessive allele
phenylketonuria accumulation of phenylalanine in blood	poor mental development and growth, weak tooth enamel	recessive allele
Tay–Sachs disease nerve cells in the brain are affected by the accumulation of gangliosides	deterioration of muscle and physical abilities	recessive allele
Huntington's disease progressive, irreversible degeneration of nervous system	loss of muscle control and cognitive abilities	dominant allele
hypercholesterolemia high levels of cholesterol accumulate in the blood	premature heart disease	dominant allele
neurofibromatosis nerve cells grow tumours	tumours may be harmless or may cause damage by pushing on other nerves	dominant allele

Ontario's Newborn Screening Program

In Ontario, newborns are currently screened for at least 28 genetic disorders. These disorders include cystic fibrosis, a number of metabolic disorders such as PKU, blood disorders including sickle-cell anemia, and disorders of the endocrine system. Even babies from families with no known history of these rare disorders are at risk.

Each year more than 140 000 newborns are tested, and of these, approximately 150 test positive for one of these rare genetic disorders. A positive result indicates the baby *may* have a genetic disorder. Only further genetic testing will confirm the presence or absence of a disease. Babies with one of these disorders often appear normal at birth but without early diagnosis may suffer irreversible damage and even death. Early diagnosis enables doctors to begin treatments that may eliminate or reduce serious health consequences and prevent infant death.

5.5 Summary

- Cystic fibrosis is a common, fatal disease passed on through a recessive mutated gene.
- Genetic counsellors construct pedigree charts and interpret results of genetic tests.
- Genetic screening is a means by which the presence of a mutated copy of a gene can be detected.
- Individuals who have the BRCA1 or BRCA2 gene mutation have a higher chance of developing breast cancer.
- Ontario's newborn screening program is used to test for many genetic disorders, including phenylketonuria and cystic fibrosis.

5.5 Questions

1. What factors may shorten the lives of people who have cystic fibrosis? K/U
2. Some people with cystic fibrosis find that athletic exercise helps their condition and keeps them in better health. Research and compare the stories of some people with CF who have become notable athletes. C A
3. Why is it important for infants to be genetically screened for PKU (phenylketonuria) at birth? K/U
4. Choose one of the disorders listed in Table 2. Use the Internet and other resources to research the following aspects of the disorder: A
   (a) symptoms
   (b) frequency of the disorder in the general population or a specific population
   (c) research currently being conducted
   (d) existence of any genetic tests or screening mechanisms available for the disorder
   (e) treatment of the disorder
5. Does the presence of a defective BRCA1 or BRCA2 gene in a woman's genes guarantee that she will develop breast cancer? Why or why not? K/U
6. Using your guidance department, the Internet, and other sources, research the educational background an individual must have in order to become a genetic counsellor. C A
7. Use the Internet and other sources to learn more about the Newborn Screening Ontario (NSO) program. K/U
   (a) Where in Ontario are the actual genetic tests conducted?
   (b) In addition to helping the newborn, for what other purposes can NSO results be used?
   (c) How old is the baby when the blood sample is taken?
   (d) The NSO program is mandatory for all newborns. Why do you think this policy was put in place?

GO TO NELSON SCIENCE

5.6 Explore an Issue in Genetic Screening

SKILLS MENU

- Defining the Issue
- Researching
- Identifying Alternatives
- Analyzing
- Defending a Decision
- Communicating
- Evaluating

Who Decides? Who Wants to Know?

Anyone could be a carrier of a genetic disorder. Every person has alleles that produce defective proteins, but most of these defective proteins do not harm us. Depending on their family history, some people might want to use gene testing to find out if there is anything in their DNA that might turn up later in life as a genetic disorder. The results of genetic tests might cause people to make life-altering changes, so the decision to have a predictive gene test can be very complicated.

A negative gene test may bring relief. For example, consider individuals at risk of developing Huntington's disease. If they find out that they do not carry the Huntington gene, they will be free of the worry of developing the disease or passing it on to their children. However, if a test for Huntington's disease turns out positive, they may be in a better position to plan for the remaining years of their life financially, socially, and emotionally.

In our society now, the decision to have a genetic test is personal. But what if genetic testing were compulsory and law enforcement agencies, employers, schools, and adoption agencies all had access to medical files on a "need to know" basis? What if you could be turned down for a job, insurance, or adoption based on a genetic test? How much information should be readily available about an individual's genetic profile, and who should have access to it? Does the average person understand enough about basic genetic principles to know how to interpret and apply information about someone's DNA? In this activity you will explore different situations involving privacy and access to genetic information.

At present in Canada, no regulation exists on the use of genetic information for purposes other than criminal investigations. Yet in the future it is plausible that an individual's genetic information could be used for other purposes. What if DNA testing were required for a marriage licence? If one of the partners is carrying a lethal allele such as the Huntington gene, should the other partner be told? The questions posed here may seem far-fetched in today's society. Yet society will be asked to consider such privacy questions in the future.

The Issue

The ethics of legal access to and ownership of DNA information needs to be considered carefully as technology for collecting and testing DNA for genetic disorders increases. Who decides? Who wants to know? Who should know? And who should be required by law to tell?

You are part of a committee that has been asked to compile a list of guidelines for a government task force that will eventually use your guidelines to compose "Access to Genetic Information" legislation. The committee consists of the following people:

- a person whose parent has Huntington's disease but does not want to be tested him- or herself
- a person whose future mother-in-law has Parkinson's disease
- an airline executive who is advocating for the genetic testing of all current and future pilots
- the president of a firm that conducts genetic tests
- a physician who advocates for genetic testing on the basis of preventive medicine
- half of a couple who wants to adopt a child

Goal

To create a set of guidelines and recommendations for access to genetic information

Research

SKILLS HANDBOOK A5.1

Work in pairs or in small groups to learn more about genetic screening in Canada. Use the Internet and other resources to research these questions:

- Which genetic disorders can be treated early if detected by genetic screening?
- Compile a list of companies in Canada that offer genetic testing. What tests are offered and at what cost? Does medical insurance cover the costs of those tests?
- What guidelines or laws currently exist in Canada with respect to access to genetic information?

WEB LINK

To start your research into these questions,

GO TO NELSON SCIENCE

Identify Solutions

SKILLS HANDBOOK A5.1

You may wish to consider the following issues:

- **Parenting:** Should parents be able to test their children for any genetic disorder regardless of evidence of risk?
- **Relationships:** Should people have access to a potential partner's genetic information? What if your partner is going to develop Huntington's disease? Should you have the legal right to know? If you are carrying a lethal gene, should the law require you to disclose this information to your prospective spouse?
- **Employment:** Should prospective employers have access to genetic information about an applicant? If so, how much of this information should be used to determine eligibility for employment? For example, should an airline be able to screen its pilots for a gene that may cause heart attacks? What if the test is later proven to be less accurate than originally thought?

Make a Decision

Create a list of recommendations or guidelines that your committee recommends with respect to the issue. Provide a rationale for each guideline and identify any stakeholders.

Communicate

In an oral presentation, present your committee's recommendations to the government task force. Your recommendations should be supported by your rationale as well as research. Remember that your audience is made up of individuals who may be guided by different principles and are seeking information

LEARNING TIP

Making Decisions as a Group

Before you come to decision as a group, make a list on chart paper of pros and cons for the question at hand. Place the chart paper where all group members can see and have access to it. This can be helpful in forming new thoughts and ideas about the issue. During a brainstorming session like this one, take an accepting attitude of all the ideas presented to the group. Wait until the page is full to critique the ideas.

Plan for Action

Tests for screening for prostate cancer and breast cancer are considered triumphs of genetic testing. The Prostate Cancer Research Foundation of Canada and the Canadian Breast Cancer Foundation both recommend early screening.

- Screening for cancer can result in fewer deaths. Find out what each foundation recommends with respect to age and frequency of screening.
- What tests are conducted to screen for each of these cancers? How do the tests work? How effective are they in preventing deaths?

Choose a type of cancer. Design and produce a pamphlet that could be used to educate people on the importance of screening for that specific cancer. Consider making a number of copies of the pamphlet and distributing them to your parents, aunts, uncles, and other people in your life who would benefit from the information you have compiled

GO TO NELSON SCIENCE

5.7 Multi-trait Inheritance

As you have learned, Mendel's monohybrid crosses were based on one characteristic controlled by one gene such as height (tall or dwarf) or seed shape (round or wrinkled) in a pea plant. As far as we currently know, genetic disorders such as cystic fibrosis and Huntington's disease each involve only one gene. What happens when more than one characteristic is involved in a cross? Gregor Mendel asked such a question and then conducted experiments to determine the answer.

Dihybrid Crosses and the Law of Independent Assortment

Mendel focused on two characteristics: seed shape and seed colour. Recall that the dominant allele for seed shape is round (*R*) while the recessive allele is wrinkled (*r*). The dominant allele for seed colour is yellow (*Y*), while the recessive allele is green (*y*). Mendel crossed two individuals that were heterozygous for seed shape (*Rr*) and seed colour (*Yy*).

dihybrid cross a cross that involves two genes, each consisting of heterozygous alleles

A cross between two individuals for two pairs of heterozygous alleles is called a **dihybrid cross**. In this case the individuals were both *RrYy*. **Figure 1** shows how Mendel used true-breeding parent plants to produce plants (the F_1 generation) that were heterozygous for these two traits. He then used these F_1 plants to perform a dihybrid cross.

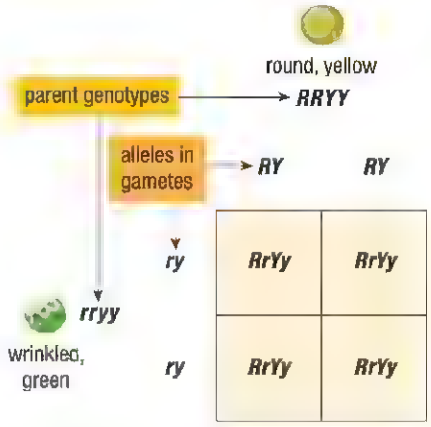


Figure 1 Mendel crossed parents that were homozygous for two traits to produce two pairs of heterozygous alleles for his dihybrid cross experiments.

A heterozygous individual for two characteristics will produce four possible gametes. A parent that is *RrYy* can generate the possible gametes *RY*, *Ry*, *rY*, and *ry*. You will see in **Figure 2** that the alleles of the two genes—*R* and *r*, and *Y* and *y*—separate independently during the formation of the gametes. This is called Mendel's **law of independent assortment**. Each allele is independent of the other, and no two alleles are linked to each other. The alleles are found on different chromosomes, creating four different gametes in different combinations of the four alleles (*R*, *r*, *Y*, *y*).

law of independent assortment If genes are located on separate chromosomes, they will be inherited independently of one another

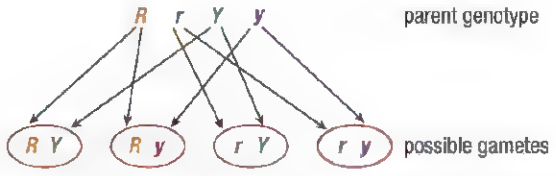


Figure 2 A pea plant that is heterozygous for both seed shape and seed colour can produce four different possible gametes. The four gametes encompass all the possible combinations. There are four possible combinations (*RY*, *Ry*, *rY*, and *ry*), and all are equally likely.

LEARNING TIP

Gene Order
When completing the Punnett square for a dihybrid cross, keep the genes in alphabetical order and write the dominant alleles (capital letters) first, for example, *GgRr*.

Mendel crossed numerous heterozygous F_1 generation plants. He then counted the F_2 offspring and noticed that the characteristics were *not* linked. He noted that although the original parents (or "grandparents" of the F_2 generation) were either round yellow or wrinkled green, the F_2 offspring characteristics were of every combination possible, including round green and wrinkled yellow. It appeared that the inheritance of seed shape had no influence over the inheritance of seed colour. Four distinct combinations of seeds were produced in a 9:3:3:1 ratio (**Figure 3**). The alleles that control these two characteristics assort themselves independently.

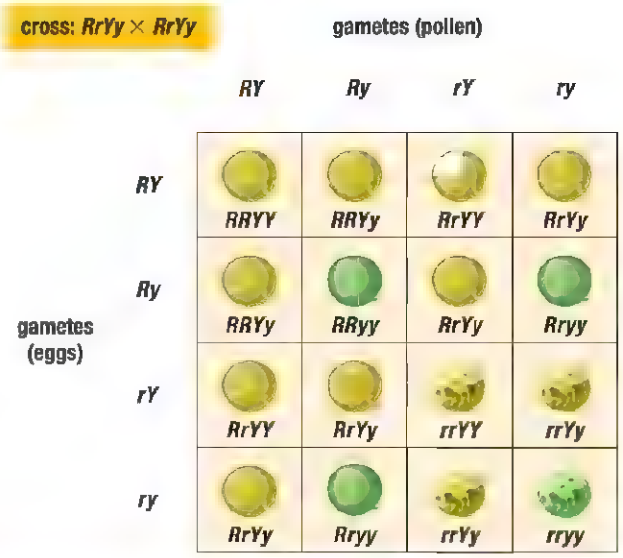


Figure 3 A summary of the dihybrid cross—9 round yellow seeds, 3 round green, 3 wrinkled yellow, and 1 wrinkled green. A dihybrid cross results in a phenotypic ratio of 9:3:3:1.

Tutorial 1 Solving Dihybrid Cross Problems

A dihybrid cross is an extension of a monohybrid cross. It involves two genes and up to four alleles.

Sample Problem 1: Determining Phenotypic Ratio

In watermelons, the green colour gene (*G*) is dominant over the striped colour gene (*g*), and round shape (*R*) is dominant over long shape (*r*). A heterozygous round green colour (*GgRr*) watermelon plant is crossed with another heterozygous round green colour (*GgRr*) plant. Determine the expected phenotypic ratio of the F_1 generation.

Step 1. Determine the possible gametes from each parent.

Each parent is heterozygous for green colour and round shape (*GgRr*). The alleles assort independently of each other. Four different gametes are produced (**Figure 4**).

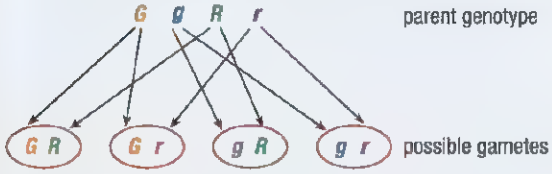


Figure 4

Step 2. Draw a Punnett square of the dihybrid cross.

Since there are four possible gametes from each parent, draw a 4 × 4 grid, with the possible gametes from one parent across the top and the possible gametes from the other parent down the left-hand side.

Step 3. Execute the cross.

Be careful when combining alleles. Work systematically across a row while keeping track of which four alleles will go into each square. Pair up the alleles for the same gene, as shown in **Figure 5**.

	GR	Gr	gR	gr
GR	GGRR	GGRr	GgRR	GgRr
Gr	GGRr	GGrr	GgRr	Ggrr
gR	GgRR	GgRr	ggRR	ggRr
gr	GgRr	Ggrr	ggRr	ggrr

Figure 5

Step 4. Compile a list of plants that have the same phenotypes.

Start with plants that will exhibit both dominant characteristics, followed by plants that are dominant for only one of the characteristics, and then finally with plants that are recessive for both characteristics.

green and round: *GGRR*, *GGRr*, *GgRR*, *GgRr*, *GGRr*, *GgRr*, *GgRR*, *GgRr*, *GgRr* (total = 9)

green and long: *GGrr*, *Ggrr*, *Ggrr* (total = 3)

striped and round: *ggRR*, *ggRr*, *ggRr* (total = 3)

striped and long: *ggrr* (total = 1)

Therefore, the phenotype ratio is 9 : 3 : 3 : 1 for a dihybrid cross.

Sample Problem 2: Examining a Homozygous Cross

Assume that in guinea pigs, black fur (*B*) is dominant over white fur (*b*), and a rough coat (*R*) is dominant over a smooth coat (*r*). If a black, rough-furred guinea pig that is homozygous dominant for both traits (*BBRR*) is crossed with a white, smooth-furred guinea pig (*bbrr*), what are the expected phenotypes in a large litter?

Step 1. Determine what the gametes will be from each parent.

Parent 1 is homozygous dominant for black and rough fur (*BBRR*). The only gamete that this individual can produce is *BR* (**Figure 6**). Parent 2 is homozygous recessive for white colour and smooth fur (*rrbb*). The only gamete that this individual can produce is *br* (**Figure 7**).

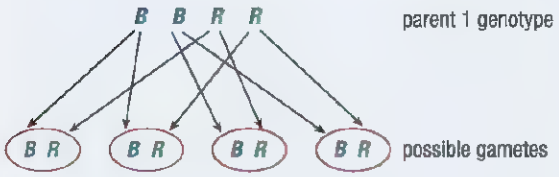


Figure 6

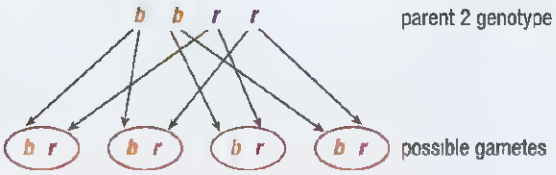


Figure 7

Step 2. Cross the gametes using a Punnett square

Since only one type of gamete is supplied by each parent, only a 1 × 1 grid is needed (**Figure 8**).

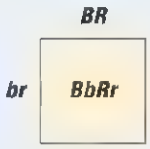


Figure 8

All of the offspring will be heterozygous for black and rough fur in any size litter.

Practice

1. In some breeds of dogs, a dominant allele controls the characteristic of barking (*B*) while on a scent trail. The allele for non-barking trailing dogs is (*b*). In these dogs an independent gene (*E*) produces erect ears and is dominant over drooping ears (*e*). For each of the following mating situations, calculate the phenotype ratio of the offspring:
   (a) A non-barking trailer with erect ears (heterozygous) is mated with a heterozygous barking trailer with drooping ears (*bbEe* × *Bbee*). [ans: non-barking trailer with erect ears: non-barking trailer with drooping ears: barking trailer with erect ears: barking trailer with drooping ears in a ratio of 1 : 1 : 1 : 1]
   (b) A non-barking trailer with drooping ears is mated with a heterozygous barking trailer with drooping ears (*bbee* × *Bbee*). [ans: non-barking trailers with drooping ears: barking trailer with drooping ears in a ratio of 1 : 1]
   (c) A heterozygous barking trailer with heterozygous erect ears is mated with a heterozygous barking trailer with heterozygous erect ears (*BbEe* × *BbEe*). [ans: barking trailer with erect ears: barking trailer with drooping ears: non-barking trailer with erect ears: non-barking trailer with drooping ears in a ratio of 9 : 3 : 3 : 1]
   (d) A heterozygous barking trailer with heterozygous erect ears is mated with a non-barking trailer with drooping ears (*BbEe* × *bbee*). [ans: non-barking trailer with erect ears: non-barking trailer with drooping ears: barking trailer with erect ears: barking trailer with drooping ears in a ratio of 1 : 1 : 1 : 1]

Probability

Genetic ratios are probabilities. Recall that if a cross occurs between two heterozygous individuals where one of the alleles is dominant, such as for widow's peak ($Ww \times Ww$), the phenotype ratio is 3:1. The total number of possible events is four, and the probability of producing an individual without a widow's peak (ww) is $\frac{1}{4}$, or 25 %. Similarly the probability of producing an individual with a widow's peak is $\frac{3}{4}$, or 75 %.

THE PRODUCT LAW

Many genetic events occur independently of one another. A couple has a 50 % chance of producing a boy for their first child. The probability of having a boy as a second child is also 50 %, because the sex of the second offspring is not affected by the sex of the first.

When two events are independent of each other, the probability that both events will occur can be calculated using the product law. The **product law** states that the probability of two or more outcomes occurring is equal to the product of their individual probabilities. The probability of giving birth to two boys is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$. Therefore, there is a 25 % chance of having two boys.

product law the probability of two independent random events both occurring is the product of the individual probabilities of the events

Recall that in a dihybrid cross the phenotypic ratio is 9:3:3:1. Consider Mendel's work with heterozygous yellow seeds crossed with heterozygous yellow seeds ($RrYy \times RrYy$). The probability of producing a round yellow seed is $\frac{9}{16}$ (about 56 %). You know that the alleles of seed colour and seed shape are independent of each other. If a cross is conducted between two heterozygous yellow seed plants (Yy), the probability of producing a yellow seed plant is $\frac{3}{4}$ (75%). If a cross is conducted between two heterozygous round seed plants, the probability of producing a round plant is $\frac{3}{4}$ (75%). Using the product rule, the probability of producing a round yellow seed plant from a cross between two heterozygous round yellow seed plants is $\frac{3}{4} \times \frac{3}{4} = \frac{9}{16}$.

The probability predicted by the product law is the same probability that is predicted by a dihybrid Punnett square. The product law also holds true for the other three probabilities in a dihybrid cross (**Table 1**).

CAREER LINK

Hybrid Research Manager

The managing of a hybrid breeding operation requires the ability to predict probable outcomes between different crosses. To learn more about careers in hybrid breeding operations,

GO TO NELSON SCIENCE

Table 1 Using the Product Law to Determine Probabilities of a Dihybrid Cross When Both Genes Are Heterozygous

Round or wrinkled seed: probability from monohybrid cross	Yellow or green seed: probability from monohybrid cross	Dihybrid cross probability
Round seed ($Rr \times Rr$) $\frac{3}{4}$ = 75 %	Yellow seed ($Yy \times Yy$) $\frac{3}{4}$ = 75 %	round, yellow seed ($RrYy \times RrYy$) $\frac{3}{4} \times \frac{3}{4} = \frac{9}{16}$ 75 % × 75 % = 56.25 %
round seed ($Rr \times Rr$) $\frac{3}{4}$ = 75 %	green seed ($Yy \times Yy$) $\frac{1}{4}$ = 25 %	round, green seed ($RrYy \times RrYy$) $\frac{3}{4} \times \frac{1}{4} = \frac{3}{16}$ 75 % × 25 % = 18.75 %
wrinkled seed ($Rr \times Rr$) $\frac{1}{4}$ = 25 %	yellow seed ($Yy \times Yy$) $\frac{3}{4}$ = 75 %	wrinkled, yellow seed ($RrYy \times RrYy$) $\frac{1}{4} \times \frac{3}{4} = \frac{3}{16}$ 25 % × 75 % = 18.75 %
wrinkled seed ($Rr \times Rr$) $\frac{1}{4}$ = 25 %	green seed ($Yy \times Yy$) $\frac{1}{4}$ = 25 %	round, green seed ($RrYy \times RrYy$) $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$ 25 % × 25 % = 6.25 %

LEARNING TIP

Sample Size

Note that Mendel observed these ratios only because of his large sample size. He crossed hundreds of plants, producing thousands of offspring. As sample size increases, the experimental (actual) probability gets closer to the theoretical (expected) probability.

Discontinuous versus Continuous Variation

In Mendel's work with pea plants, the genes that control two characteristics did not interact with each other. This is the result of **discontinuous variation**. Pea plants were tall or short, and seeds were yellow or green. There were no in-between values.

discontinous variation when the expression of the products of one gene has no bearing on the expression of the products of a second gene

continuous variation when the product of one gene is affected by the product of another gene, the gene products may be additive, or one product may negate another product

additive allele an allele that has a partial influence on a phenotype

As you no doubt have noticed, there are many examples in nature where this is not the case. **Continuous variation** is when the phenotypic variation is not clear cut. For example, in the general population there are many variations of skin colour, from pale white to dark black. This is because skin colour is not controlled by one gene, but rather by three or more separately inherited genes from the father and mother. The genes are on different autosomal chromosomes and their interaction is additive. An **additive allele** contributes a set amount to a phenotype and is an example of continuous variation. Skin colour varies depending on which combination of six alleles the offspring inherit from parents. Each allele makes its own contribution and exhibits incomplete dominance.

Other alleles may also play a role. For example, alleles for freckles and red hair have a role in determining skin colour. Other traits that are under the control of additive alleles are height, hair colour, and eye colour. Continuous variation explains the substantial variation of phenotypes found in nature.

5.7 Summary

- Dihybrid crosses are crosses between individuals who differ in two pairs of alleles; if individuals are heterozygous for both alleles, the phenotype ratio of the offspring is 9:3:3:1.
- Mendel's law of independent assortment states that alleles of different genes separate into gametes independently of each other.
- The probability of two independent events both occurring may be calculated using the product law.
- Punnett square ratios are one way to show probability.
- Discontinous variation occurs when a trait is either expressed or not. There is no in-between trait.
- Continuous variation occurs in nature when the expression of a characteristic is the sum of the expression of all alleles involved.

5.7 Questions

1. State Mendel's law of independent assortment. Provide an example that illustrates the law. K/U
2. List the possible gametes from the following individuals: K/U
   (a) a widows-peaked (heterozygous), attached-earlobe individual
   (b) a free-lobed (heterozygous), albino individual
   (c) a dwarf, yellow seed colour (homozygous) pea plant
3. Assume that curly hair (*C*) is dominant to straight hair. Albinism (*P*) is recessive to normal skin pigmentation. A woman who is heterozygous for curly hair and albinism has a child. The father is homozygous dominant for curly hair and has albinism. K/A
   (a) Determine the possible phenotypes for their child
   (b) Calculate the four different probabilities of a child being both a male and of each phenotype.
   (c) What is the probability that the child will express albinism and have curly hair like his father?
4. Assume that in horses, black coat colour is dominant (*B*) to chestnut colour (*b*). The trotting gait is due to a dominant allele (*T*), and the pacing gate is a recessive allele (*t*). K/U
   (a) If two black trotting horses are mated and have four offspring, all of which are black and pacing, what does that reveal about the probable genotypes of the parent horses?
   (b) A stud is black and trotting. He is mated with a mare who is also black and trotting. Their colt is black and pacing. The same stud is mated to a second mare who is chestnut and pacing. Their colt is chestnut and trotting. What is the probable genotype(s) of the stud, mare 1, colt 1, mare 2, and colt 2?
5. In your own words, differentiate between continuous and discontinuous variation. K/U
6. Design an experiment in which you could determine whether height in tomato plants is governed by continuous variation or discontinuous variation. T/I
7. The alleles for human blood types A and B are codominant, but both are dominant over the type O allele. The Rh factor is separate from the ABO blood group and is located on a separate chromosome. The Rh+ allele is dominant over the Rh−. Indicate the possible phenotypes from mating a woman with type O, Rh−, with a man with type A, Rh+. The man is homozygous for type A and heterozygous for Rh factor. K/U
8. Why is sample size important in a genetic investigation? A
9. Is it possible to have a trihybrid cross? Explain your thinking. T/I

CHAPTER 5 Investigations

Investigation 5.2.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Gummy Bear Genetics

Mendel derived his laws of inheritance by counting the number of different types of offspring that resulted from different crosses of peas and then analyzing the results. Using a large sample size provided Mendel with enough data to see trends. The trends in the data led to the development of Mendel's law of inheritance.

In this investigation you will be given a sample of "offspring" from a Mendelian monohybrid cross. By sorting and counting the number of offspring, you will be able to determine the genotypes of the parents that produced the offspring.

Purpose

To determine the genotypes of parents by counting and sorting the phenotype ratios of the offspring

Equipment and Materials

- labelled bags containing gummy bears

This is a laboratory procedure. Food is not to be eaten in the laboratory.

Procedure

SKILLS HANDBOOK A2.4

1. Copy **Table 1** into your notebook.

Table 1 Phenotype Ratios of Gummy Bears in Individual Bags

Monohybrid cross bag label	Total number of gummy bears	Phenotypes and numbers	Phenotype ratio	Genotypes	Parental cross
A					
B					
C					

2. Obtain a bag of gummy bears from your teacher and record the letter label of the bag.
3. Empty the contents of the bag onto your desk. Count the gummy bears and record the total in Table 1.
4. Sort the gummy bears into groups based on phenotype differences that can be easily observed and quantified, such as colour.
5. Count and record the number of bears of each phenotype in Table 1.
6. Repeat Steps 2 to 5 for each of the different (A, B, C, . . .) bags available from your teacher.

Analyze and Evaluate

(a) For each bag, calculate the phenotype ratio of bears in the bag. Record this ratio in Table 1. T/I

(b) Determine which bear colour is dominant and which bear colour is recessive. Use *T* to represent the dominant allele and *t* to represent the recessive allele. **Hint:** Look at the phenotype ratio of Bag C. T/I

(c) Use the ratios and your knowledge of Mendelian genetics to determine the likely genotype(s) of each type of bear found in the bags. Record these genotypes in Table 1. T/I

(d) Determine the genotypes of the parents that produced the offspring in each of the bags. Record this information in Table 1. T/I

(e) For each bag, draw a Punnett square to show that the cross of the genotypes you predict for the parents will produce the ratio that you observed. T/I

Apply and Extend

(f) Why is having a large number of gummy bears in each bag important? T/I

(g) Pool your class data in **Table 2**. T/I

Table 2 Phenotype Ratios of Gummy Bears—Class Results

Monohybrid cross bag label	Total number of gummy bears	Phenotypes and numbers	Phenotype ratio	Genotypes	Parental cross
A					
B					
C					

(h) Why are the ratios not exactly the same as Mendel's ratios? T/I

(i) What type of inheritance does each of the three monohybrid crosses represent? T/I

(j) Design a set of bags that would represent the phenotype ratios found in crosses that involve alleles that exhibit incomplete dominance. What colours of gummy bears would you use? How many of each? What type of cross would you execute? T/I A

Investigation 5.3.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

My Genetic Profile

The individuals of every population have a variety of phenotypes. These variations are a result of genotypic variance caused by the inheritance of different alleles. The presence or absence of an allele inherited according to the Mendelian laws of inheritance can be followed through many generations with a pedigree chart.

In this activity you will identify your phenotype for eight characteristics and use these observations to try to determine the associated genotypes. Then you and a partner will determine the phenotypes and genotypes for possible first- and second-generation offspring and construct a pedigree chart.

Purpose

To determine your phenotype and genotype for a characteristic and to track allele inheritance through three generations

Equipment and Materials

- coin

Procedure

SKILLS HANDBOOK A2.4

Part A: Determining Your Genotype

1. Copy **Table 1** into your notebook.

Table 1 Genotypes for Some Common Human Phenotypes

Characteristic	Dominant phenotype	Recessive phenotype
dimples	present (*D*)	absent (*d*)
earlobes	freely hanging (*F*)	attached (*f*)
hair on mid-finger	hair present (*H*)	hair absent (*h*)
2nd toe longer than big toe	longer (*L*)	shorter (*l*)
hairline	widow's peak (*W*)	straight (*w*)
tongue roll	roller (*R*)	non-roller (*r*)
thumb flexibility	bent back (*T*)	straight (*t*)
thumb placement with hands clasped	left thumb on top (*P*)	right thumb on top (*p*)

2. Using the information in Table 1 as a guide, draw and complete a data table similar to **Table 2** that lists all eight characteristics. If, for a particular trait, you do not know whether you are homozygous dominant or heterozygous, record your genotype as heterozygous.

Table 2 Determining Your Genotype

Characteristic	Phenotype	Possible genotype(s)
dimples		
earlobes		

Part B: The F_1 Generation

Now you will work with a partner to simulate the passing on of genetic information to a single offspring. For this activity, ignore sex.

3. Copy **Table 3** into your notebook, with rows for all eight characteristics.
4. To determine the genetic makeup of the offspring, you and your partner (parent 1 and parent 2) must each contribute a single allele for each characteristic. To choose each allele, you must make eight coin flips—one for each characteristic. If you flip "heads," you contribute the first allele of your genotype; if you flip "tails," you contribute the second allele. For example, if you flip heads for "thumb flexibility" and you are *Tt*, then you enter *T* under your parent column in Table 3.
5. After you have determined the alleles for each characteristic, complete the genotype and phenotype columns in your table.

Table 3 Genotype and Phenotype of F_1-Generation Offspring

Characteristic	Allele from parent 1	Allele from parent 2	Genotype	Phenotype
dimples				
earlobes				

Part C: The F_2 Generation

Now you will simulate the mating of your offspring with the offspring of another pair of students.

6. Repeat Step 4 to model the contribution of alleles from the two F_1 offspring and determine the genotype and phenotype of their F_2 offspring—your "grandchild" in this simulation. Record your data in a new copy of Table 3 titled "Genotype and Phenotype of F_2-Generation Offspring."
7. Choose any single trait in your grandchild and draw a pedigree chart to track its inheritance over the three generations. Be sure to include all four grandparents and both parents in the chart.

Analyze and Evaluate

(a) In this activity, which step(s) represent(s) an event in meiosis? Is this a true representation? Why or why not? T/I

(b) Use examples from the activity to explain your understanding of the terms "genotype," "phenotype," "recessive," and "dominant." T/I C

(c) Look at your table of genotypes and phenotypes. How many of your eight traits are recessive? T/I

(d) Look at your partner's table. How many of his or her eight traits are recessive? T/I

(e) How did the number of recessive traits in your offspring compare with that of yours as "parents." Did this surprise you? What factors might account for these differences? T/I

(f) Write a birth announcement for one of your offspring. List the baby's characteristics. T/I C

Apply and Extend

(g) Tally the class results and calculate the percentage of traits that were recessive for the class as a whole. T/I

(h) Based on the class data, do you think dominant phenotypes are always more or always less common than their corresponding recessive phenotypes? Use examples to support your answer. T/I C A

CHAPTER 5 SUMMARY

Summary Questions

1. Look back at the Key Concepts listed at the beginning of the chapter, on page 182. Create a graphic organizer with the word "inheritance" in the middle to organize the main ideas and concepts presented in this chapter.
2. Look back at the Starting Points questions at the beginning of the chapter, on page 182. Use examples from the chapter to answer the questions again. Compare your latest answers to your initial answers. Note how your answers have changed.

Vocabulary

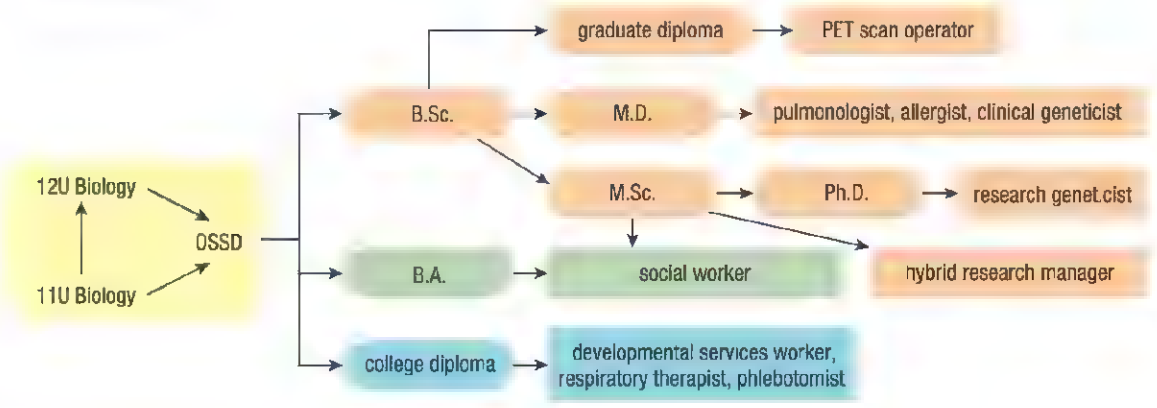
trait (p. 184)
true-breeding organism (p. 184)
hybrid (p. 184)
cross (p. 185)
P generation (p. 185)
F_1 generation (p. 185)
monohybrid (p. 185)
monohybrid cross (p. 185)
F_2 generation (p. 185)
law of segregation (p. 186)
allele (p. 187)
homozygous (p. 187)
heterozygous (p. 187)
genotype (p. 187)
phenotype (p. 187)
dominant allele (p. 187)
recessive allele (p. 187)
Punnett square (p. 188)
probability (p. 188)
test cross (p. 190)
complete dominance (p. 194)
incomplete dominance (p. 194)
codominance (p. 195)
pedigree (p. 197)
autosomal inheritance (p. 200)
sex-linked (p. 200)
X-linked (p. 200)
Y-linked (p. 200)
mutation (p. 204)
carrier testing (p. 204)
genetic screening (p. 204)
phenylketonuria (PKU) (p. 205)
dihybrid cross (p. 210)
law of independent assortment (p. 210)
product law (p. 213)
discontinuous variation (p. 213)
continuous variation (p. 214)
additive allele (p. 214)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or postgraduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select two careers related to genetic processes that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



GO TO NELSON SCIENCE

CHAPTER 5 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. If a true-breeding pea plant with yellow seeds is crossed with a true-breeding pea plant with green seeds, what is the probability that the F_1 generation will have green seeds? (5.1) K/U
   (a) 0 %
   (b) 25 %
   (c) 75 %
   (d) 100 %
2. The hereditary units that Mendel called "factors" are known today as
   (a) genes
   (b) traits
   (c) chromosomes
   (d) characteristics (5.1) K/U
3. In snapdragons, a cross between a red-flowering snapdragon and a white-flowering snapdragon will produce snapdragons that have pink flowers. This is an example of
   (a) complete dominance
   (b) codominance
   (c) incomplete dominance
   (d) X-linked dominance (5.2) K/U
4. In humans, the blood type allele I^A shows complete dominance when paired with
   (a) the allele *i* only
   (b) the allele I^B only
   (c) the allele *i* or the allele I^B
   (d) neither the allele *i* nor the allele I^B (5.2) K/U
5. In a pedigree you know a trait is recessive if
   (a) both parents of the affected individual have the same trait
   (b) neither parent of the individual has the same trait
   (c) the mother has the trait but the father does not
   (d) the father has the trait but the mother does not (5.3) K/U
6. How are Y-linked disorders passed on? (5.3) K/U
   (a) from father to daughter
   (b) from father to son
   (c) from mother to daughter
   (d) from mother to son
7. Which disorder is a dominant trait? (5.5) K/U
   (a) cystic fibrosis
   (b) Tay–Sachs disease
   (c) hemophilia
   (d) Huntington's disease
8. Which is the genotype of an individual that could be used in a dihybrid cross? (5.7) K/U
   (a) *RRYY* (c) *RrYY*
   (b) *RRYy* (d) *RrYy*
9. In a family with three children, what is the probability that the first child is a boy, the second child is a girl, and the third child is a boy? (5.7) K/U
   (a) 12.5 % (c) 50 %
   (b) 25 % (d) 75 %

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

10. In genetics, the mating of two organisms is called an allele. (5.1) K/U
11. Recessive alleles are expressed only when both alleles are the same. (5.1) K/U
12. An individual's outward appearance for a particular characteristic is his or her phenotype. (5.1) K/U
13. Each parent passes along one allele for each gene. (5.1) K/U
14. A Punnett square is a diagram that can be used to predict the outcome of a cross between two organisms. (5.1) K/U
15. If the chance of event A is 25 % and the chance of event B is 10 %, then the chance of both event A and B occurring is 35 %. (5.1) K/U
16. AB blood type in humans is an example of incomplete dominance. (5.2) K/U
17. On a pedigree chart, an affected female is indicated by a shaded square. (5.3) K/U
18. In autosomal inheritance, males and females are affected equally. (5.3) K/U
19. A trait that occurs in all of the males of a family and none of the females is probably X-linked. (5 3) K/U
20. An individual who is heterozygous for the allele that causes cystic fibrosis is called a carrier. (5.5) K/U
21. Neurofibromatosis is a genetic disorder that is a recessive trait. (5.5) K/U
22. Height is an example of a human characteristic that shows discontinuous variation. (5.7) K/U
23. Skin colour is a human characteristic affected by additive alleles. (5.7) K/U
24. An individual with the genotype *RrGG* can produce gametes with three different allele combinations. (5.1, 5.7) K/U

To do an online self-qu z,
GO TO NELSON SCIENCE

CHAPTER 6

Genetics beyond Mendel

KEY CONCEPTS

After completing this chapter you will be able to

- describe the structure of DNA
- explain how DNA accounts for transmission of hereditary characteristics
- describe the key characteristics of the human genome and how it compares to other genomes
- outline the ways genes can be manipulated within a genome and between genomes
- provide examples of where gene therapy has been successful and where it has fa led
- explain how the manipulation of genomes has far-reaching consequences for society and the environment

What Is DNA? How Does DNA Code for Life?

In 2003, the Human Genome Project was completed. Thousands of scientists from around the world had worked collaboratively to read the entire set of human genetic instructions. Surprising findings came out of the project. Humans have the same number of genes as a mouse and a chicken but fewer than a corn plant. Does that mean that humans are similar to mice and chickens? Phenotypically, no, but genotypically, yes.

Researchers are now focused on determining where the genes are located within the genome, and what each gene codes, or gives instructions, for. The first step is to determine the DNA sequence of each gene. After a gene sequence has been determined, researchers need to find out what the gene does. Research can then focus on trying to figure out what has happened if a gene is not coding for the correct biochemical product. For example, what is the gene coding for, or not coding for, in conditions such as cystic fibrosis, Huntington's disease, and Parkinson's disease? Why? Researchers know the function of only about half of human genes so far.

Once researchers determine why a gene is not working, they can try to develop a genetic therapy to offset the effect of the defective gene. Genetic therapy research is still in the experimental stage. It has had limited successes and many setbacks. Scientists have achieved limited success with conditions such as type 1 diabetes, Duchenne muscular dystrophy, and deafness. Genetic procedures have to be perfected in animals such as mice and guinea pigs before human experimental trials can take place. Every day, scientists are working toward successful human genetic therapy.

In this chapter you will study the structure of DNA and how DNA structure codes for the diversity of life. You will explore what happens when there is a change, or mutation, in the DNA code. In addition, you will take a closer look at the human genome and compare it to genomes of other species. Finally, you will explore the emerging fields of genetic engineering and gene therapy, including groundbreaking research and applications of new genetic technology.

STARTING POINTS

Answer the following questions based on your current knowledge. You will have an opportunity to revisit these questions later, applying concepts and skills from the chapter.

1. What is DNA?
2. How might an understanding of the genetic code benefit individuals and society?
3. How might changes in an organism's DNA code be positive? How might changes in an organism's DNA code be negative?
4. What do you think are some of the the ethical considerations associated with genetic technology?

Mini Investigation

DNA Extraction

Skills: Predicting, Performing, Analyzing, Evaluating

SKILLS HANDBOOK A2.1

Deoxyribonucleic acid (DNA) is the molecule that codes for life. It is found in all organisms, from microscopic one-celled paramecia to elephants, which have trillions of cells. In this investigation you will extract DNA strands from strawberries.

Equipment and Materials: eye protection; lab apron; graduated cylinder; beaker; medium-sized test tube; stirring rod; strawberries; sealable plastic bag; extraction buffer; filter paper; ice-cold ethanol

1. Put on your lab apron and eye protection.
2. Predict what you think the extracted DNA will look like.
3. Place 3 or 4 strawberries in a medium-sized sealable plastic bag.
4. Squeeze out the air from the bag and seal the bag. Crush the strawberries into juice and pulp.
5. Open the bag and add 10 mL of extraction buffer.
6. Reseal the bag. Mix the strawberry juice with the extraction buffer.
7. Use the filter paper to filter the strawberry juice–extraction buffer mixture into a beaker.
8. Transfer the mixture from the beaker to a medium-sized test tube until the test tube is one-third full.
9. Slowly pour 3 mL of ice-cold ethanol down the side of the test tube so that it forms a layer on top of the strawberry filtrate. Observe the precipitate that forms where the two liquids meet.
10. Wait 2 to 3 min. Insert a stirring rod into the test tube. Spool the DNA out.

A. Describe the appearance of the DNA. T/I C

B. What is the purpose of the extraction buffer? The cold ethanol? T/I

C. Why do you think the DNA can be spooled onto the stirring rod? T/I

D. Describe the purity of your DNA sample. Explain your thinking. T/I

6.1 DNA and the Code of Life

Figure 1 A human chromosome

nuclein the original name given to DNA when it was discovered in the nucleus of cells by Friedrich Miescher in 1869

When a child has the same colour hair or the same-shaped nose as one of his or her parents, it is said that there is a family resemblance. Throughout history, humans have had many ideas about what type of substance might be passed from parent to child that accounts for family resemblances. Before the exact molecule responsible for heredity was identified, Mendel and other scientists determined that genes, carried on chromosomes (**Figure 1**), control phenotypic characteristics. Chromosomes are passed from parents to offspring through gametes. In this way, the diversity of individuals, and indeed the diversity of all life, is a reflection of the different genes organisms inherit.

The Discovery of DNA as Genetic Material

Modern science has shown that deoxyribonucleic acid (DNA) is the molecule that stores and transmits genetic information from parents to offspring. Many scientists have contributed to the discovery of the hereditary molecule DNA.

The story began in 1869 when Friedrich Miescher, a Swiss scientist, investigated a compound found in the nucleus of the cells he studied; Miescher called this compound **nuclein** (now known as DNA). After Miescher's discovery, numerous scientists conducted experiments in an attempt to determine if nuclein was the material that stored and passed on genetic information. The chemical components of nuclein were discovered in the 1920s, but it took decades of research before it was proven that DNA is responsible for heredity.

In the 1930s, Danish biologist Joachim Hammerling verified that genetic material was contained in the nucleus. Hammerling's experiments involved large, green, single-celled algae called *Acetabularia* that have three distinct regions: a foot, a stalk, and a cap. Using a microscope, he saw that the foot contained the nucleus. In his first experiment, he cut off the cap of several algal cells, and the algae were able to regenerate new caps. In the second experiment, he cut off the foot, but this time none of the algal cell regenerated (**Figure 2**). Therefore, he reasoned, the material that was directing new growth must be located in the nucleus, found in the foot. Hammerling could not verify what the genetic material was, only that it was found in the nucleus. This experiment was a vital step in the study of genetics.

WEB LINK

To learn more about the discovery of DNA,

GO TO NELSON SCIENCE

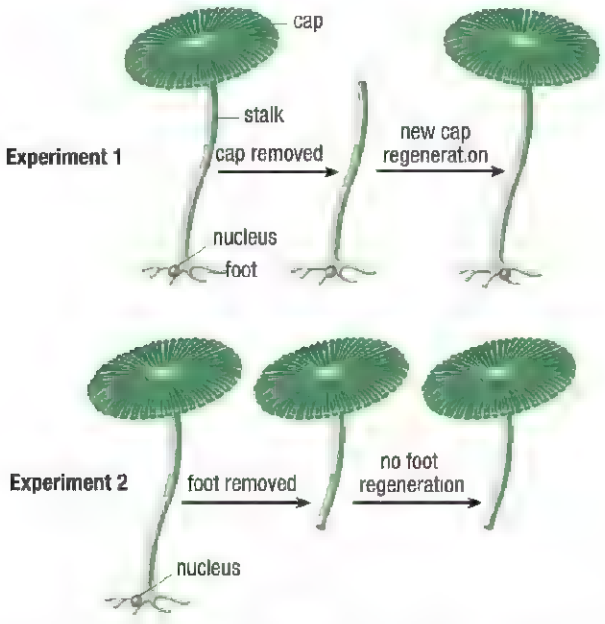


Figure 2 Since a new cap grew only from an existing foot that contained the nucleus, Hammerling concluded that the nucleus must contain the hereditary material.

At this point, scientists hypothesized that DNA was the hereditary material. However, the hypothesis was not proven until 1952, when Alfred Hershey and Martha Chase conducted experiments using a bacterial virus. Bacterial viruses invade bacterial cells and then use the organelles found in the bacteria to produce more bacterial viruses. Hershey and Chase showed that the viruses needed only to inject their DNA into the bacteria to produce more bacterial viruses. They concluded that DNA directed the production of new viruses and that DNA was the hereditary material.

Although Hershey and Chase worked only with bacteria, they realized that the idea could be applied to all organisms. Their discovery confirmed the work done by Hammerling, who had concluded that hereditary material is located in the nucleus.

The Chemical Composition of DNA

In the 1920s, Phoebus Levene discovered that DNA had three main components:

- a pentose sugar (a cyclic, 5-carbon sugar)
- a phosphate group that has a negative charge
- a nitrogenous base

Together, the three components are called a **nucleotide**. About 3 billion pairs of nucleotides make up the human genome. There are four possible bases for the nucleotides of DNA: adenine (A), guanine (G), thymine (T), and cytosine (C) (**Figure 3**).

nucleotide the repeating unit in DNA; it comprises a deoxyribose sugar, a phosphate group, and one of the four nitrogenous bases

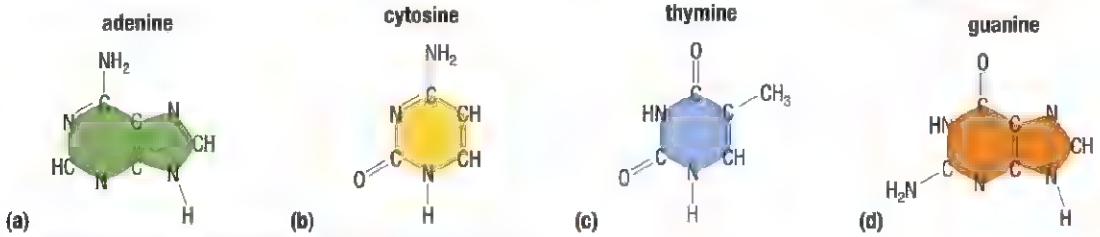


Figure 3 The four nitrogenous bases, A, C, T, and G, in DNA

In 1940, Erwin Chargaff discovered a key relationship among the nitrogenous bases in DNA:

- The amount of adenine (A) is always equal to the amount of thymine (T).
- The amount of guanine (G) is always equal to the amount of cytosine (C).

Figure 4 shows a nucleotide, comprising a phosphate group, a pentose sugar, and a nitrogenous base. Notice from the figure that DNA has a negative charge because of the phosphate ions in its chemical backbone.

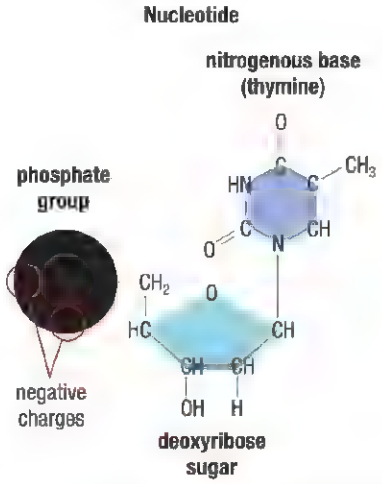


Figure 4 The three main components of DNA are shown here (with thymine as the nitrogenous base).

The Structure of the DNA Molecule

Scientists had now gathered a great deal of information about the chemical composition of DNA, but they were still missing a few pieces of the puzzle. To understand how DNA stores and transmits genetic information, scientists needed to establish the precise structure of the molecule.

X-ray crystallography a technique in which a pure substance is subjected to X-rays; the pattern in which the X-rays bend and spread helps reveal the structure of the pure substance

In 1951, researcher Rosalind Franklin began to study DNA using **X-ray crystallography.** Working together with another scientist, Maurice Wilkins, Franklin determined that DNA molecules form a helix, or corkscrew, shape (**Figure 5**).

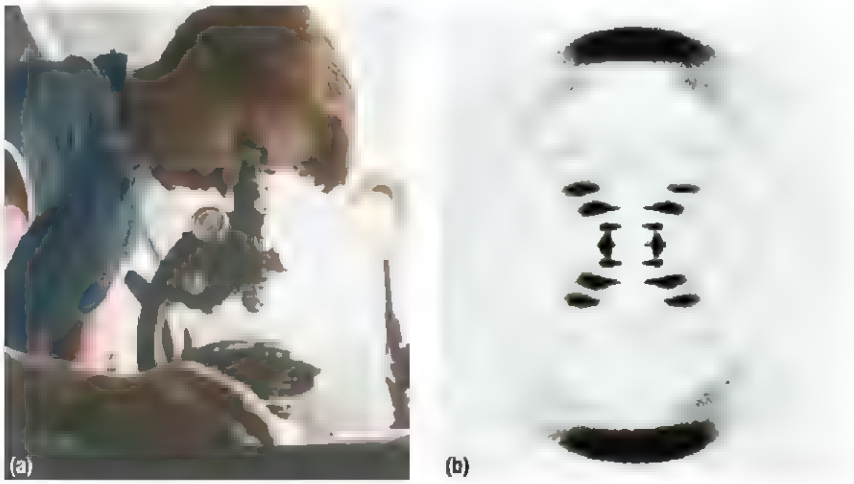


Figure 5 (a) Rosalind Franklin used X-ray crystallography to reveal the helical structure of DNA. In this technique, a crystal of DNA is exposed to X-rays in order to produce (b) a diffraction pattern. The diffraction pattern can then be used in an effort to reconstruct the positions of the atoms in the molecules of DNA.

Figure 6 James Watson and Francis Crick with their model of a DNA molecule, which integrated all of the chemical information that was known about DNA at the time

In 1953, James Watson and Francis Crick, two scientists at Cambridge University, met with Wilkins, who shared the information he and Franklin had discovered. Using what they knew about the chemical structure of DNA, Watson and Crick built a model of DNA. Watson and Crick's model showed the molecular structure of DNA to be a double helix (**Figure 6**). This model was based on a single X-ray diffraction image that Franklin had taken, as well as on other chemical information about DNA that was known at the time. Their model accounted for the following information, discovered and shared by other scientists:

1. DNA is made of a pentose sugar, a phosphate group, and one of four nitrogenous bases (Levene, 1920s).
2. The proportion of adenine (A) to thymine (T) is equal. The proportion of cytosine (C) to guanine (G) is equal (Chargaff, 1940).
3. DNA has the shape of a helix or corkscrew (Franklin and Wilkins, 1951).

Watson and Crick used this information to put together all the "puzzle pieces" provided by their peers when creating their molecular model of DNA. Franklin's X-ray images of DNA crystals were of the highest quality, and were instrumental in Watson and Crick's final determination of the structure of DNA (now widely accepted as being accurate).

A Model for DNA

scientific model a simplified representation of a concept; can be tangible or conceptual

A **scientific model** can be a representation of a system or a concept. Watson and Crick built on the work of the scientists before them to create their model of DNA. Using this information, they proposed that DNA is made up of two strands of repeating DNA nucleotides that run in opposite directions.

The chemical backbone of a DNA strand is made up of alternating phosphate groups and pentose sugars. Attached to this backbone are nitrogenous bases: adenine,

guanine, cytosine, and thymine (**Figure 7**). The bases of one strand are paired with the bases of the other strand in the following arrangement:

- Thymine (T) is always bonded to adenine (A).
- Cytosine (C) is always bonded to guanine (G).

This type of pairing is known as **complementary base pairing**. Watson and Crick proposed a complementary base-pairing molecule in order to explain Chargaff's observations of equal proportions of bases.

complementary base pairing pairing of the nitrogenous base of one strand of DNA with the nitrogenous base of another strand; adenine (A) pairs with thymine (T), and guanine (G) pairs with cytosine (C)

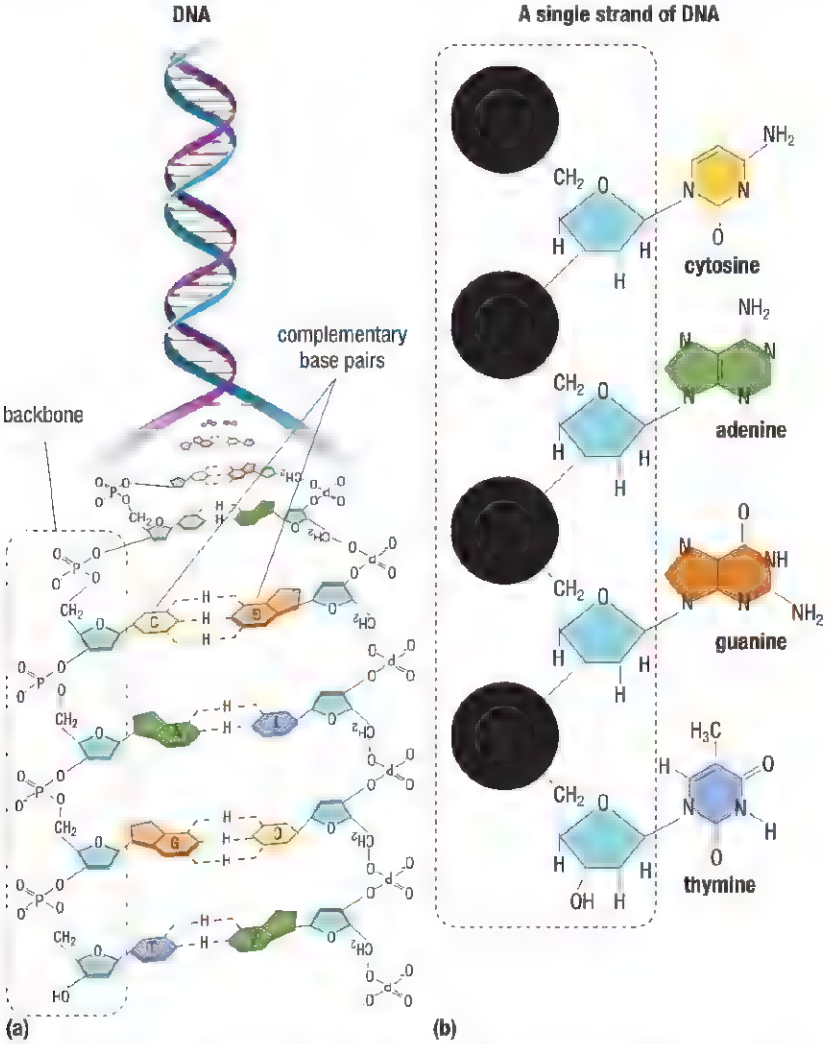


Figure 7 DNA is double stranded. The outer backbone consists of alternating pentose sugar and phosphate groups. The inner part of the molecule contains the complementary bases.

Since the bases are complementary, there is no need to know the nucleotide base sequence for both strands. Once the nucleotide base sequence is determined for one strand, the sequence on the complementary strand can be determined easily. For example, the complementary base sequence for ATGGCCATC would be TACCGGTAG. **Figure 8** shows more examples.

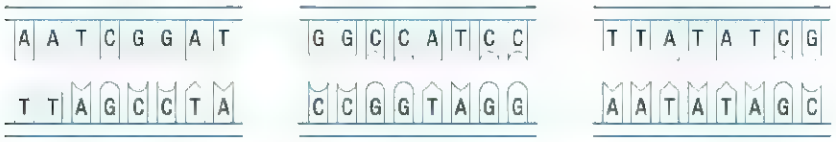


Figure 8 Examples of complementary base pairing. T always pairs with A and G always pairs with C.

LEARNING TIP

DNA Twist

DNA exists as a right-handed double helix as well as a left-handed double helix. The two types of helix are mirror images of each other. Watson and Crick built a model of a right-handed helix.

Mini Investigation

Origami DNA

Skills: Performing, Observing, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1

Scientists build models to better understand a concept. Watson and Crick used information about the chemical composition of DNA to build a model of DNA. Once the structure was determined, the chemical mechanisms of processes involving DNA, such as chromosome replication, could be further investigated.

In this activity, you will build a model of DNA using the ancient Japanese art of origami (paper folding). There are two types of folds: mountain folds and valley folds. In mountain fold, the crease is toward you (**Figure 9(a)**). In a valley fold, the crease is away from you (**Figure 9(b)**).

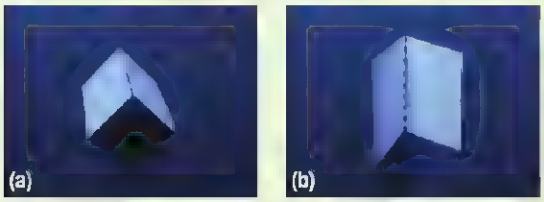


Figure 9 (a) A mountain fold (b) A valley fold

Equipment and Materials: scissors; ruler; DNA origami handout

1. Cut around the blank trim on your handout.
2. Make mountain folds for all of the solid vertical lines down the page. Make valley folds for all of the dashed vertical lines down the page (**Figure 10**).
3. Bring the two sides of the model together.
4. Hold the model so that the side labelled "front" is facing you. Fold the two sides of the DNA model so that the front side is flat (**Figure 11**).

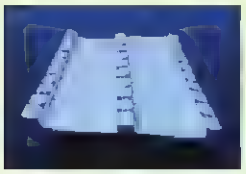


Figure 10

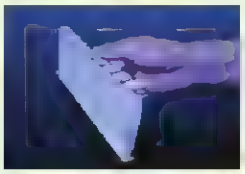


Figure 11

5. Make a mountain fold for each solid horizontal line on the front side (**Figure 12**).
6. Flip the model so that the side labelled "back" is facing you. Make a mountain fold for each solid diagonal line on this side (**Figure 13**).

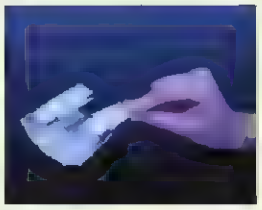


Figure 12 Folded horizontal lines

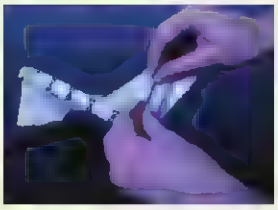


Figure 13 Folded diagonal lines

7. Fold all the creases together in the directions of the folds made in Steps 5 and 6. The model should fold up like an accordion. As you are folding, pinch the middle of the model to keep it together to make a cylindrical (or helical) shape as in **Figure 14**.
8. Release the model. Straighten out the sides of the model (the DNA backbone) so that the sides are perpendicular to the creases made in Steps 5 and 6. Your model should have a helical shape (**Figure 15**).

Figure 14 When you complete the folding, you will be able to hold the model in one hand.

Figure 15

A. Compare your model to the known structure of DNA. How does it compare? TI

B. Identify the backbone and the nitrogenous bases in your model. TI

C. The human genome has 3 billion base pairs. There is a turn every 10 nucleotides, a distance of 3.4 nm. Measure the distance of 10 nucleotides on your model. By what factor does your model have to be reduced to attain the actual size of the DNA molecule? TI

D. How long would your paper model have to be in order to represent 3 billion base pairs? TI

6.1 Summary

- Deoxyribonucleic acid (DNA) stores and transmits genetic information from parent to offspring.
- DNA is made up of repeating nucleotides. Each nucleotide consists of a sugar, a phosphate group, and a nitrogenous base.
- DNA has four nitrogenous bases: thymine (T), cytosine (C), adenine (A), and guanine (G).
- Thymine (T) and adenine (A) are complementary bases. Guanine (G) and cytosine (C) are complementary bases.
- James Watson and Francis Crick determined the structure of DNA. DNA consists of two strands that run in opposite directions. Each strand is made up of alternating phosphate and sugar molecules with nitrogenous bases attached to the backbone.

6.1 Questions

1. Outline the contributions of the following scientists in the determination that DNA is the hereditary material: K/U
   (a) Joachim Hammerling
   (b) Alfred Hershey and Martha Chase
2. What does DNA stand for? What are the three main components of DNA? K/U
3. Identify and explain Chargaff's contribution to the determination of DNA structure. K/U A
4. What is the complementary strand of TTGACAGTAAAA? A
5. Describe Watson and Crick's model of DNA. How does it account for all the experimental evidence about DNA composition that was known at the time? K/U C
6. Rosalind Franklin's work was key to understanding the structure of DNA. Conduct online research to learn more about her scientific accomplishments.
   (a) Describe her contributions to the understanding of DNA and viruses.
   (b) Why was she not nominated for the Nobel Prize in 1962?
   (c) Do you think she deserved more recognition than she received? Why or why not? T/I C A
7. Pick two of the experiments that were described in this section. For each one, identify the following.
   (a) What were the controlled and responding variables?
   (b) What hypothesis did the researchers use?
   (c) How did the researchers build up the evidence to draw their conclusion? K/U T/I A

GO TO NELSON SCIENCE

6.2 Mutations

Your body makes billions of cells in a day. As your body constantly produces new copies of existing cells, whether for growth, reproduction, or maintenance, it must replicate your DNA billions of times. Recall from Chapter 5 that a change in the genetic code of an allele is called a mutation.

Figure 1 Radiation warning signs are placed in areas where nuclear waste is present. This is in part because exposure to radioactive materials can cause genetic mutations.

point mutation a small-scale change in the nitrogenous base sequence of a DNA; the mutation may be beneficial, harmful, or neutral (having no effect on the organism)

Types of Mutations

Mutations can be caused by environmental agents such as damaging radiation (**Figure 1**) and certain chemicals, or as errors during cell division. A mutation may have a positive, negative, or neutral effect on the phenotype of the individual. Some gene mutations result in the new cell dying and being recycled. However, sometimes cells carrying mutations survive and replicate.

Point Mutations

One type of mutation that can occur during DNA replication is called a **point mutation**. A point mutation is a failure by the replicating cell to copy the genetic information accurately. There are several types of point mutations, including three major ones: base-pair substitutions, insertions, and deletions.

In a base-pair substitution, one nitrogenous base is accidentally replaced with a different base. In an insertion, one or more nitrogenous bases are inserted during the copying process. In a deletion, one or more nitrogenous bases are deleted during the copying process.

Figure 2 shows the three types of point mutations. In each case, the sequence of nucleotides is altered. Ribosomes assemble proteins based on this sequence. The ribosomes read the sequence in groups of three nucleotides. If a change is made in the sequence of nucleotides, the ribosomes will read an altered sequence and assemble a different protein.

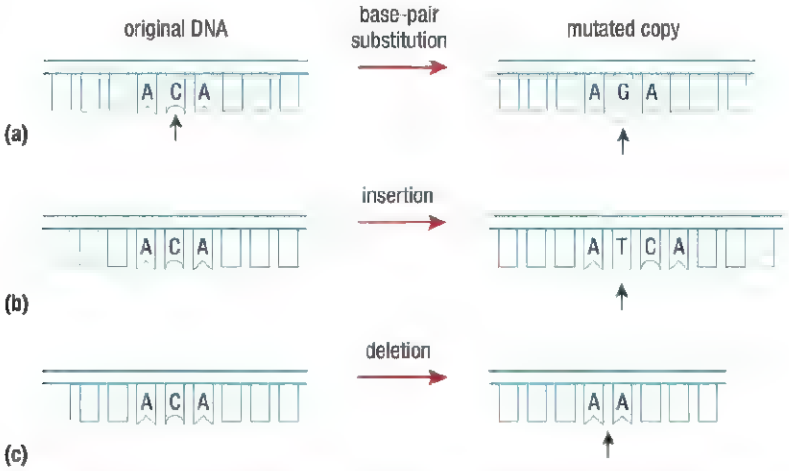


Figure 2 (a) In a base-pair substitution, one nucleotide is replaced by a different nucleotide. (b) In an insertion, a nucleotide is added. (c) In a deletion, one nucleotide is eliminated. When a mutation occurs, both strands of the DNA molecule are affected. Only the changes in a single strand are shown here.

Chromosome Mutations

chromosome mutation an error that involves an entire chromosome or a large part of a chromosome

Errors that involve an entire chromosome or a large part of a chromosome can also occur. A mutation at this scale is known as a **chromosome mutation**. An example of a chromosome mutation is non-disjunction. Recall from Chapter 4 that non-disjunction occurs when sister chromatids fail to separate during meiosis. This results in the production of gametes that contain too many or too few chromosomes.

Down syndrome is a genetic disorder that results from non-disjunction of chromosome 21. Characteristics of Down syndrome include short stature, heart defects, and developmental delays. Many important agricultural crops, such as wheat, cotton, and potatoes, have gametes with complete sets of extra chromosomes that do not cause them any harm.

Other chromosomal mutations involve large-scale deletions, insertions, or inversions (flipping) of entire portions of a chromosome—each containing many thousands of bases.

Inheriting Mutations

Mutations can occur as the DNA in an organism's cells is copied. Most mutations occur in parts of the DNA that do not code for genes. Many mutations that do occur are immediately corrected during the copying process. However, as organisms age, mistakes during mitosis occur more frequently and can lead to diseases such as cancer.

Mutations that occur in body cells (autosomes) are not passed on to offspring and therefore cannot affect future generations. In contrast, mutations that occur in sex cells (gametes) can be passed on to offspring. DNA that mutates in an egg or the sperm that fertilizes it becomes part of the DNA of the zygote. This means that the new individual will have a copy of the mutation in every cell of its body and will be able to pass on the mutation to future generations.

If the mutation is dominant, it could be expressed phenotypically in the first generation (as with Huntington's disease). If a mutation is recessive, it will likely not be expressed for many generations until, by chance, two individuals with the same mutation produce a homozygous recessive mutation in their offspring.

Consider the CFTR (cystic fibrosis transmembrane conductance regulator) allele that causes cystic fibrosis. There are various forms of this defective gene, but each CFTR allele was first created by a mutation event in the DNA of a sex cell from a previous generation.

Sickle-Cell Anemia

A mutation that has been passed on through generations can be neutral, harmful, or beneficial. In some cases, a mutation seems to be both harmful and beneficial. For example, individuals with sickle-cell anemia (SCA) have inherited a mutated gene in which a single adenine base was substituted by a thymine. Healthy red blood cells, which carry oxygen throughout the body, are round. In SCA, blood cells can become C-shaped when oxygen levels are low in the cell (**Figure 3**). The shape of sickle cells does not allow them to move through blood vessels properly. As a result, blood flow is impaired and the cells must be removed and destroyed.

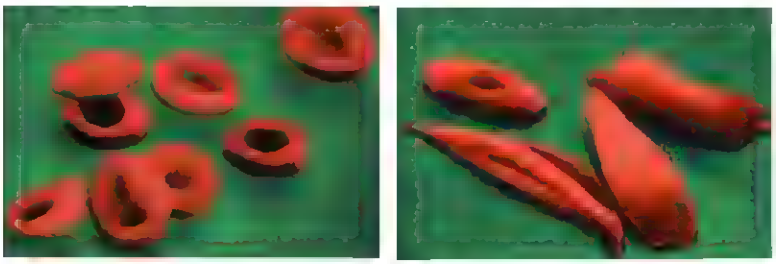


Figure 3 C-shaped sickle cells are more fragile than regular-shaped red blood cells and are easily destroyed in the blood stream.

Although the mutation for SCA can cause negative health effects including pain and an increased risk of infection, the sickle-cell gene also has a beneficial property. One of the world's most serious parasitic diseases is malaria. It is widespread in many tropical parts of the world, including central Africa, where it kills close to 1 million people each year. However, if the malarial parasite enters a red blood cell of an individual with SCA, oxygen levels in the cell drop and it becomes sickle shaped. The infected red blood cell is then removed from the blood by the body and destroyed—killing the parasite in the process. In this way, the sickle-cell mutation has proven to be a very beneficial mutation in the parts of Africa where it has become relatively common.

Lactose Intolerance and Tolerance

Lactose intolerance is a very common trait in which a young adult or adult individual is unable to digest lactose, the common sugar in milk. People who are lactose intolerant do not produce enough of the enzyme needed to digest lactose. If people who are lactose intolerant consume a lot of dairy products, undigested lactose will be metabolized by intestinal bacteria. This can result in bloating, cramping, and diarrhea. The severity of the symptoms is quite variable, so some people are unaware that they have inherited this trait.

Throughout much of human history, before the domestication and milking of livestock, adults never consumed milk. When babies are born, they are lactose tolerant and produce the enzyme to digest their mother's milk. As they grow, most human children lose their ability to produce the enzyme to digest milk and therefore become lactose intolerant. About 75 % of the adults in the world are lactose intolerant. The remaining percentage of adult humans who can tolerate lactose are able to do so because of a genetic mutation. Individuals who have inherited the mutated gene for lactose tolerance continue to produce the enzyme throughout their lives.

This mutation is an example of a gene mutation that has become very beneficial in cultures that have domesticated livestock for milk production. Both forms of the gene (tolerant and intolerant) are relatively common, but the proportion of tolerance varies with geography, depending on the agricultural history of the population (**Figure 4**). Scientists hypothesize that the mutation that produced lactose tolerance occurred and spread in the human population some time after the domestication of dairy animals such as the goat and cow about 7000 years ago.

Figure 4 (a) Asian cuisines have very few cows' milk–based dishes because a high percentage of Asian people are lactose intolerant. (b) European cultures consume milk and other dairy products such as cheese and milk-based desserts. Most European people are lactose tolerant.

In 2002, researchers identified the gene on human chromosome 2 that is responsible for lactose tolerance. People can now have a genetic test to help determine if they are lactose intolerant or not.

spontaneous mutation a mutation that is not caused by any outside factors; it occurs randomly

induced mutation a mutation that occurs because of exposure to an outside factor; second-hand smoke increases the chance of developing lung cancer

Spontaneous or Induced?

What causes a mutation to occur? Some mutations occur naturally, while others occur after exposure to an outside agent that causes the change. **Spontaneous mutations** are those that happen in nature by accident. They are a result of incorrect copying of DNA during the replication of chromosomes in mitosis and meiosis.

Induced mutations are a result of exposure to a physical or chemical agent that causes a mutation, such as radiation or cigarette smoke. For example, there is a direct correlation between exposure to harmful UV rays and induction of a mutation that causes skin cancer (**Figure 5**). The incidence of skin cancer is most prevalent in Australia, where UV rays are very strong throughout much of the year. Lung cancer is also caused by an induced somatic cell mutation—it does not get passed on to offspring. Smoking or inhaling second-hand smoke increases the risk of developing lung cancer.

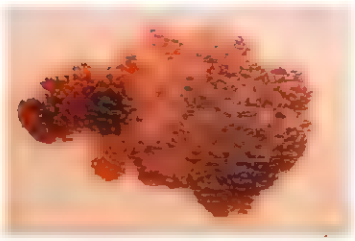


Figure 5 Prolonged exposure to damaging UV light rays can lead to skin melanoma (a type of skin cancer).

Antibiotic Resistance

In 1928, Alexander Fleming went away on holiday. When he returned, he noticed that some mould had grown on a Petri dish of bacteria he was researching. The mould had killed all the nearby bacteria. Fleming had serendipitously discovered the first antibiotic that would be produced on a large scale for fighting bacterial infections: penicillin.

As you learned in Chapter 2, the widespread use of antibiotics has created a new set of problems. Some bacteria are naturally resistant to antibiotics. Others may become resistant through gene transfer or genetic mutation. Either way, resistant bacteria are able to survive exposure to antibiotics and pass the genes that make them resistant to the next generation. Throughout the years since Fleming's discovery, as doctors have prescribed antibiotics, more and more resistant bacteria have been able to survive. Now there are many strains of bacteria that are no longer susceptible to one or more types of antibiotic. They are **antibiotic resistant**.

antibiotic resistant describes strains of bacteria that are no longer susceptible to the effects of antibiotics; are sometimes called "superbugs" and are prevalent in hospital settings

Recall that one way antibiotics kill bacteria is by interfering with cell wall production. The antibiotic binds to a molecule in a bacterium's cell wall. In fact, antibiotics are often engineered specifically to match certain bacterial cell wall components. When the antibiotic comes in contact with it, the cell wall is weakened and the bacterium bursts and dies. However, if the gene that produces the cell wall molecule has experienced a mutation, the antibiotic may not be able to bind to the cell wall. The antibiotic then becomes useless against the bacteria. The mutation is beneficial to the bacteria, as the cell wall remains intact. The mutated bacteria will survive and pass on their mutation to the next generation.

Jumping Genes and Barbara McClintock

Point mutations are examples of mutations that occur within genes at fixed locations. In the 1940s, geneticist Barbara McClintock challenged the idea that genes always remain in a fixed position (**Figure 6**). McClintock conducted experiments using corn that produces a variety of coloured kernels—white, yellows, oranges, reds, and even purples. Every kernel is an individual corn plant embryo, so one cob produces a very large sample size of offspring (**Figure 7**). This feature makes corn an ideal organism in which to study genetic patterns.

Figure 6 Barbara McClintock proposed the theory of transposons in the 1940s. She was awarded a Nobel Prize in 1983.

Figure 7 In corn, different genes and combinations of genes result in the patterns and range of colours found in the kernels.

McClintock's work with corn led her to suggest that an organism's genome is not static, but rather that there are segments of DNA that can move as a unit from one location to another. McClintock called these movable segments **transposons**, or "jumping genes." The process of moving from one section of the genome to another section of the genome is **transposition**. Transposons can move from one place to another on the same DNA molecule, or they can move between DNA molecules. For example, transposons can affect the colour of corn kernels. If a transposon is inserted into the gene for purple kernels, the gene is disrupted and purple pigment cannot be produced—the resulting kernels are white.

transposon a specific segment of DNA that can move along or between the chromosomes

transposition the process of moving a gene sequence from one part of the chromosome to another part of the chromosome

Recall from Chapter 5 that hemophilia is an inherited condition caused by a defect in a gene for a certain blood-clotting factor on the X chromosome. In rare cases, hemophilia may also be caused by a transposon. If a transposon inserts itself into a normal blood factor VIII gene, then the individual, if male, will be affected by hemophilia (**Figure 8**). Since hemophilia is an X-linked trait, both X chromosomes need to be affected in order for a female to be affected by hemophilia.

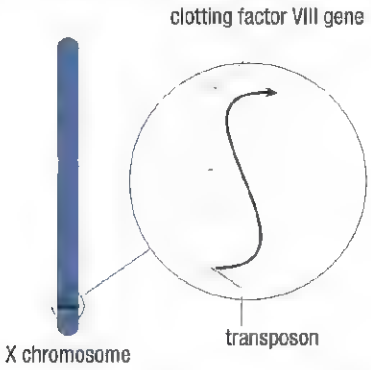


Figure 8 Here, a transposon has jumped and become inserted into a blood-clotting factor gene on the X chromosome. Note that transposons can also jump from one chromosome to another, and some transposons leave copies of themselves behind.

McClintock did her pioneering work in the late 1940s, before the structure of DNA was known. Her work was revolutionary and was not widely accepted by the scientific community until much later. Today, scientists recognize that transposons exist in virtually all large genomes and are an important cause of mutation.

Microarray Technology

The identification of genes that lead to genetic disorders is at the forefront of genetic research. The discovery of the genes that cause cystic fibrosis and Huntington's disease has enhanced our understanding of how these diseases are inherited. It has also led to cutting-edge research into their treatment and prevention.

In the past, the search for a gene was like searching for a needle in a haystack. A new technology, called microarray technology, simplifies the search for disease-causing genes. A **microarray** consists of a small membrane or glass slide that contains samples of hundreds, or even thousands, of DNA fragments arranged in a regular pattern. Each fragment corresponds to a particular gene. Samples with genetic material to be tested are spread over the microarray chip and interact with these gene fragments (**Figure 9**).

microarray a small membrane or glass slide that has been coated in a predictable and organized manner with a genomic sequence

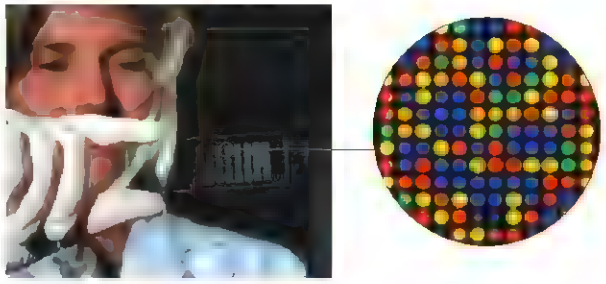


Figure 9 A sample of a microarray. Each spot on the array is associated with a particular gene sequence. Depending on the colour and intensity of colour, the array can reveal if a particular gene is active and/or mutated.

Parkinson's disease is a neurodegenerative disease. Individuals with Parkinson's experience uncontrolled tremors, loss of balance, slowness and stiffness, and rigidity of muscles. The mutation that causes Parkinson's disease was discovered in just nine days using microarray technology.

To further appreciate the value of microarray technology, consider the following example. Suppose a researcher wants to know which genes might be responsible for a particular form of liver cancer. The researcher obtains cells from the liver tumour and from non-cancerous liver cells. If the identical set of genes are active in the normal cells and in the cancer cells, then the researcher has found no evidence for genetic influence. However, if a particular gene is active in all normal cells but not active in any of the cancer cells, then this suggests a possible mutation and link between the cancer and a mutated inactive gene. Conversely, the researcher might find a gene that is always active in cancer cells but never active in healthy liver cells. This suggests that a mutation has produced an abnormally active gene and a possible link to the disease.

WEB LINK

Microarrays in Motion

To watch a simulation of a microarray technology experiment,

GO TO NELSON SCIENCE

6.2 Summary

- A mutation is change in the genetic code of an allele.
- Examples of point mutations are base-pair substitutions, insertions, and deletions. All result in a different protein being built by ribosomes.
- Lactose intolerance is the inability to digest lactose. Conversely, lactose tolerance is the ability to digest lactose. Lactose tolerance is the result of a mutation.
- Bacteria have developed antibiotic resistance due to mutations including those in the gene that directs the shapes of cell wall building-block molecules.
- Transposons are sequences of DNA that can move along and between chromosomes, possibly causing a change in an organism's phenotype.

6.2 Questions

1. Create a concept map that shows the terms and concepts from this section and how they are related. K/U T/I C
2. How does a mutation cause a change in the protein made by a cell? K/U
3. Examine the following DNA sequence and determine what type of mutation, if any, produced the sequences below:

   ...TAACGCATTT...

   (a) ...TAAGGCATTT...

   (b) ...TAAGCATTT...

   (c) ...TAACGCATTTT...

   (d) ...TACGCAGTTT... K/U T/I A
4. Explain, using an example, how it is possible for a mutation to be harmful in some circumstances but beneficial in others. K/U A
5. (a) What is lactose intolerance?

   (b) What advantage do people who are lactose tolerant have compared to those who are lactose intolerant?

   (c) Certain populations worldwide are much more lactose intolerant than others. Why might this be the case?

   (d) Indigenous people of the Americas did not domesticate livestock for milk production. Predict whether or not these people will have a high or low incidence of lactose tolerance. Conduct online research to check your prediction. K/U T/I A
6. What is microarray technology? K/U
7. Define transposons. K/U
8. Use the Internet and other sources to research four chemicals that humans are exposed to that are known to cause cancer. Make a table listing the chemicals, where they are found, and what sorts of cancers they can cause. T/I C A

GO TO NELSON SCIENCE

6.3 Genomes

Human Genome Project (HGP) a collaborative worldwide project to sequence the nitrogenous bases in human DNA

In 1990 an ambitious project called the **Human Genome Project (HGP)** was launched. The goal of the HGP was to determine the complete 3 billion nitrogenous base sequence of human DNA. More than 2000 scientists from around the world collaborated to crack the code of the human DNA (**Figure 1**). Information about their research was exchanged among scientists by email, by articles in scientific journals, and by sharing when they met at conferences or visited each other's laboratories. In 1998, a private company, Celera Genomics, joined the race and, using a more computerized approach, began their own efforts to read the human genome.

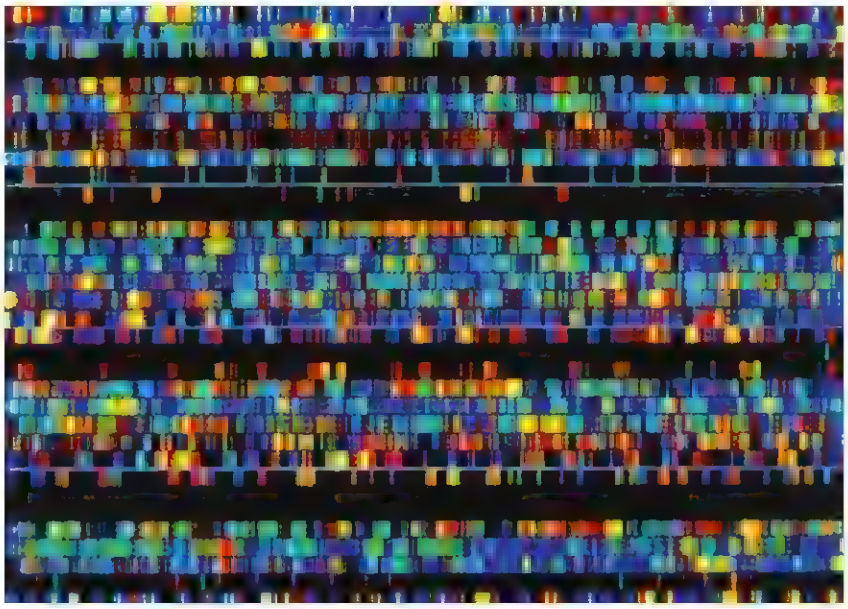


Figure 1 This computer screen displays a human DNA sequence as series of coloured bands. Each colour represents a specific base.

The Human Genome

In 2000, Celera Genomics and the HGP announced simultaneously that they had deciphered the human genome sequence, and each institution published a working draft in the prestigious journals *Science* and *Nature*. Three years later a more complete version was announced: 2.85 billion nucleotides had been sequenced

The HGP team collected blood from females and sperm from males in a large sample of anonymous donors. Only a few samples were processed as DNA resources, and the source names remain confidential, so neither the donors nor scientists know whose DNA was sequenced. Celera collected samples from five donors who identified themselves only by race and sex.

human genome the sequence of DNA nitrogenous bases found on the 23 sets of chromosomes in humans

coding DNA a region of DNA that contains a sequence of nucleotides that will be expressed; a gene

non-coding DNA a region of DNA that does not contain a sequence of nucleotides that will be expressed

The **human genome** is made up of about 3 billion base pairs. A base pair is a nucleotide on one strand of the DNA molecule bonded weakly to its complementary nucleotide on the other strand of the DNA molecule. Not all base pairs encode genes, but the regions of the genome (or sequence of bases) that do code for a gene are called **coding DNA**. Coding DNA may make up as little as 2 % of the human genome. The remaining 98 % consists of highly repetitive DNA sequences called **non-coding DNA**, or "junk" DNA. A small portion of this non-coding DNA may serve important functions, but scientists are almost certain most of it does not.

Other Genomes

The largest genome that has been sequenced so far is a freshwater amoeboid that is made up of 670 billion base pairs. A large percentage of the DNA in this organism is non-coding DNA. The number of genes is not proportional to genome size—a larger genome does not necessarily mean a greater number of genes. At present, it is believed that humans have about 20 000 genes. **Table 1** shows a comparison of the number of genes in other organisms.

Table 1 Number of Genes Believed Present in Different Genomes

Organism	Size of genome	Approximate number of genes
amoeba	670 billion	unknown
newt (salamander)	84 billion	unknown
wheat	17 billion	unknown
human	3 billion	20 000
mouse	2.6 billion	25 000
Asian rice	446 million	50 000
fruit fly	137 million	13 602
yeast	12.1 million	6 034
E. coli	4.6 million	3 200
influenza virus	1.8 million	1 700

Functional Genomics

The HGP was the first step in understanding humans at the molecular level. Now that we know the sequence of nitrogenous bases, further research is being conducted to isolate genes and determine their function. Information gathered about genes and their functions is known as **functional genomics**.

functional genomics the study of the relationship between genes and their function

The mapping of the human genome has led to some medical advances. Genetic tests can predict such diverse matters as whether people with breast cancer need chemotherapy or whether individuals are at risk for eye disease. The information that the HGP has provided is invaluable as medical researchers search for the mutated genes that cause many genetic disorders. Yet researchers still have many questions. The human genome is complex. Scientists study other organisms that are genetically similar to humans. An organism that is used in place of another organism to study biological functions is a **model organism**. Surprisingly, mice are ideal model organisms for humans. Mice share many similarities to humans with respect to nitrogenous base sequence, gene location, and coding and non coding regions.

model organism an organism that can be used to study biological functions of another organism, due to its genetic similarity

Mice and humans have roughly the same number of base sequences in their genome as other mammals, such as dogs, cats, rabbits, and monkeys (**Figure 2**). Mice and humans also share a similar number and type of genes, and most genes found in humans also exist in mice. Variation between the gene products may exist, of course, but the type of gene is similar. For example, both mice and humans have genes that code for hemoglobin, but mouse hemoglobin differs slightly from human hemoglobin. However, it is obvious that the interaction of the genes must differ, since phenotypically mice are significantly different from humans.

Figure 2 Mammals contain roughly the same number of nitrogenous bases—3 billion—in their genome and about the same number of genes.

Knowing that a single change in the nitrogenous base sequence can result in disorders such as cystic fibrosis, sickle-cell disease, and breast cancer, it is not surprising that there is not much difference between the genomes of humans and apes. (**Figure 3**).

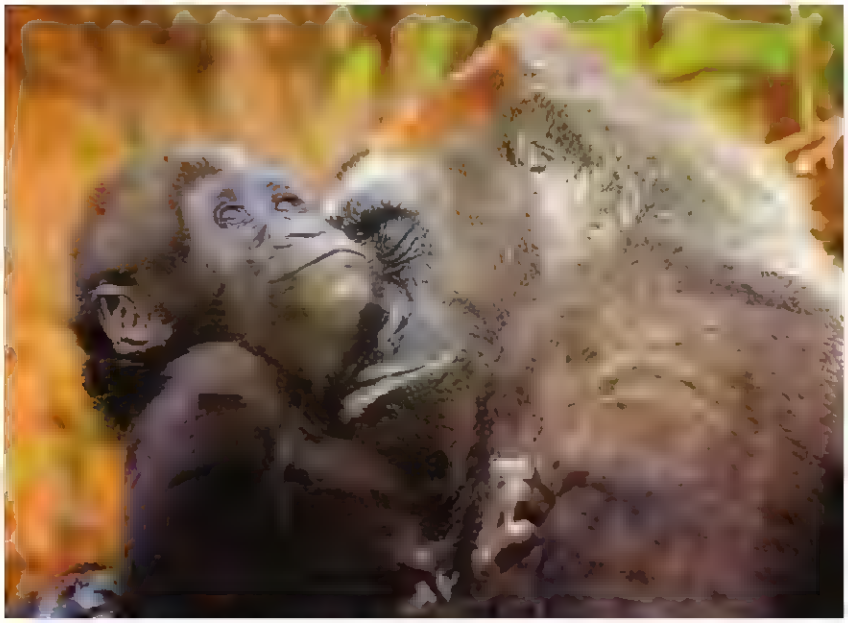


Figure 3 There is a 95 % to 98 % similarity between the genomes of humans and apes.

CAREER **LINK**

Bioethicist
Bioethicists examine the controversies and concerns that arise as advances in science and technology are applied in fields such as medicine, genetics, and biotechnology. To learn more about being a bioethicist,

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DNA Identification

When the Human Genome Project was in the planning stages, valid questions about the implications of the project arose. Who would have access to an individual's genome? Would this lead to mandatory DNA sampling in the future when applying for employment? University? College? Would governments begin to take DNA samples from all new infants for storage and possible use?

DNA information is, for the most part, still personal and private (unless you are suspected of performing criminal acts). DNA information is not required for making any of the above decisions. Bioethicists provide information to society so that informed decisions may be made on difficult questions.

People can now have their DNA screened for numerous genetic disorders, such as Huntington's disease and cystic fibrosis. Many private companies offer genetic testing and DNA banking. When DNA is stored in a **DNA bank**, it is not studied or sequenced; the DNA is simply frozen and stored for future use. To use a DNA bank, a person must supply a blood sample. The DNA is extracted from the blood and then stored in a freezer for an amount of time depending on company policy.

DNA bank a database of DNA sequences; the sequences can be from plants, animals, or humans

DNA banks also store the DNA of endangered species. Scientists are not able to bring back extinct species with current technology, but no one is sure what the future holds. So far, geneticists have sequenced fragments of DNA from extinct animals and have used bacteria to produce the protein that the fragment codes for. As you will learn in the next unit, geneticists have even sequenced the entire genome of a Neanderthal—an extinct hominid that lived more than 30 000 years ago. Some DNA banks store DNA samples of plants and fish. Researchers have access to the information in these banks that may be used to develop more viable agricultural species.

DNA Fingerprinting

In order to compare the DNA of a suspect to the DNA at a crime scene, a technique known as DNA fingerprinting is used. **DNA fingerprinting** produces a pattern of bands on a gel that is characteristic of each individual but highly variable from person to person. Forensic detectives perform multiple tests and compare many bands from each sample. If every band on the suspect's gels match every band from the crime scene sample, then it is highly likely that the suspect was at the crime scene (**Figure 4**).

DNA fingerprinting a pattern of bands on a gel that is unique to each individual

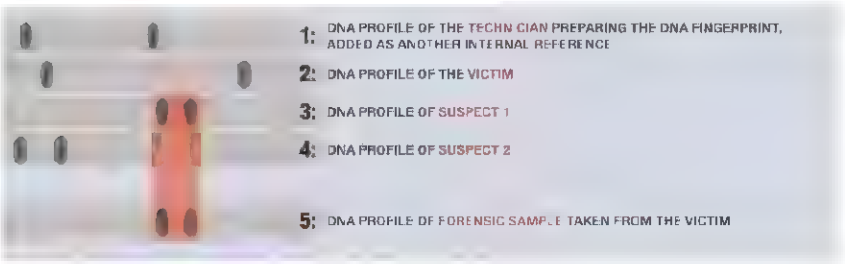


Figure 4 The DNA fingerprint of suspect 1 matches the DNA fingerprint of the sample (possibly blood, semen, or hair) that was found at the crime scene. Forensic detectives make multiple gels and often compare 10 or more bands.

DNA fingerprinting is used to illustrate innocence as well as guilt. For example, David Milgaard spent more than 20 years in prison in Saskatchewan before DNA fingerprinting technology was available. When the DNA evidence provided by Milgaard was compared to stored crime scene samples, it proved that the DNA at the crime scene was not his. In this case, DNA evidence showed that it was impossible for Milgaard to have committed the crime, and he was released from prison in 1999, having been wrongfully convicted.

DNA fingerprinting may be used to settle paternity suits, determine ancestry, locate long-lost relatives, or identify remains, such as those of soldiers in unmarked graves. Currently, paternity suits are the most common application of DNA fingerprinting. DNA fingerprinting proves the genetic relationship between children and their biological parents, siblings, or even grandparents.

DNA fingerprinting applications are very widespread, including some in consumer affairs. Recently, researchers at the University of Guelph found that many fish products labelled as one type of fish were in fact another type of fish. Wildlife enforcement officers use DNA fingerprinting to prosecute hunters or fishers who hunt or fish certain animals out of season, or endangered species. Animal meat that has been packaged and stored in a freezer can be difficult to identify. DNA fingerprinting can reveal the true source.

National DNA Data Bank

In Canada, it is legal for a judge to request blood or hair samples from suspects in criminal cases and convicted criminals to be added to Canada's DNA Data Bank. The bank holds the DNA sequence of thousands of convicted criminals. The information in the bank allows the police to

- link crimes together when there are no suspects
- help identify suspects
- eliminate suspects when there is no match between the crime scene DNA and the suspect's DNA
- determine whether a serial offender is involved

Many cases have been solved, and criminals have been prosecuted, with the use of forensic DNA evidence. In addition, innocent people accused of a crime have been exonerated by DNA evidence.

WEB LINK

Using DNA Data to Solve Crimes
To read about how Canada's DNA bank has been used to solve crimes,

GO TO NELSON SCIENCE

Investigation 6.3.1

Comparing DNA Fingerprints (page 254)

Now that you have learned about DNA fingerprinting you can complete Investigation 6.3.1.

In this investigation you will compare two samples of DNA to a known sample.

6.3 Summary

- The Human Genome Project and Celera Genomics successfully sequenced the 3 billion base pairs in the human genome.
- Different genomes contain different numbers of genes. The human genome contains approximately 20 000 genes.
- The mouse genome is very similar to the human genome in gene function. Mice are good model organisms for human genetic studies.
- DNA banks can be used to store DNA for future use. DNA data banks also store the DNA of endangered species and plants, as well as fish.
- DNA fingerprinting is a technique that may link a suspect to a crime scene.
- Forensic DNA evidence is frequently used in Canadian criminal trials and even in fish and wildlife enforcement.
- The National DNA Data Bank in Canada stores the DNA of convicted criminals.

6.3 Questions

1. Differentiate between the human genome and the Human Genome Project. K/U
2. When did the Human Genome Project commence? When was it completed? K/U
3. Compare the mouse genome to the human genome. How are they similar? How are they different? K/U
4. Why are mice a good model for studying human genes? K/U
5. Using the Internet and other sources, research the term "knockout mice." Use a flowchart to explain how knockout mice are used in gene research. T/I C
6. What is a DNA data bank? List the different ways a data bank may be used. K/U
7. What is DNA fingerprinting? Why is it an effective forensic tool? K/U
8. The DNA fingerprint shown in **Figure 5** was produced after a crime had been committed. Which of the suspects could have committed the crime? T/I

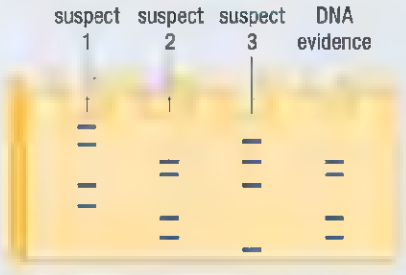


Figure 5

9. Use the Internet and other sources to research a Canadian case where DNA evidence was used to exonerate or convict a suspect in a human crime or a fish and wildlife crime. T/I A
10. Use the Internet and other sources to research the number of species for which entire genomes have been sequenced. T/I A
    (a) List at least e ght species that you researched.
    (b) Comment on the types of organisms that have been sequenced. Suggest reasons as to why these types of species may have chosen for genome sequencing.
11. Visit the website of the Human Genome Project (HGP). Read the website, and conduct research to answer to the following questions. T/I A
    (a) Do all chromosomes have the same number of genes?
    (b) Do genes seems to be spread out evenly along each chromosome?
    (c) How was the HGP funded?
    (d) Who has access to the information?

GO TO NELSON SCIENCE

Manipulating the Genome

6.4

In the early 1970s, American researchers Stanley Cohen and Herbert Boyer performed a series of experiments that resulted in a way to select, recombine, and introduce new genes into bacteria. Although this was important scientific work, the commercial value of the experiments was uncertain at the time.

Today, the genetic engineering techniques developed by Cohen and Boyer are used to insert genes from one organism into another. Bacteria can be manipulated to produce insulin for people with diabetes, botanists can modify crops to make them herbicide resistant, and genetic researchers can study the role of individual genes by inserting them into other organisms that normally do not carry that gene. Mammals, birds, fish, insects, worms, plants, fungi, and bacteria have all been manipulated genetically for a variety of purposes, including research into how the human body functions and how disease arises.

The Tools of Genetic Engineering

Two tools are used to cut out a gene from one organism and insert it into another: plasmids and restriction enzymes. Recall from Chapter 2 that plasmids are small circular pieces of DNA that can exit and enter bacterial cells (**Figure 1**). **Restriction enzymes** are like chemical scissors that can cut DNA at specific sequences (**Figure 2**). After the DNA is cut, each end has a short set of exposed complementary bases called "sticky ends." The same restriction enzyme always creates the same matching sticky ends.

restriction enzyme a molecule that has the ability to cut DNA at a specific site; different restriction enzymes recognize and cut different sites

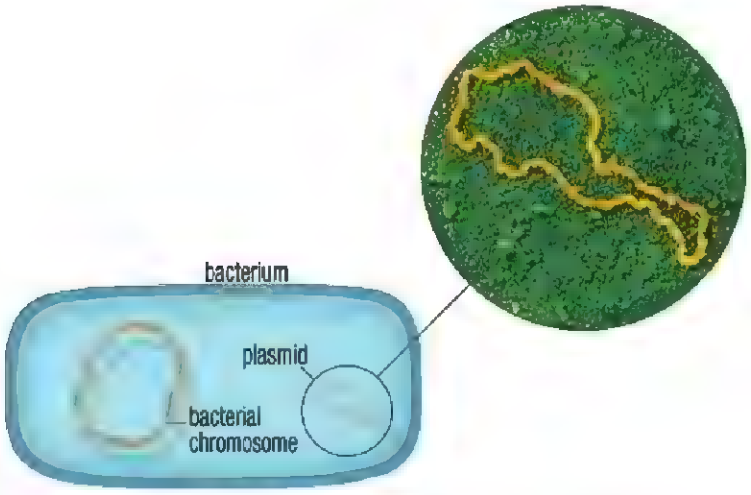


Figure 1 Plasmids are rings of DNA that have the ability to enter and exit a bacterial cell

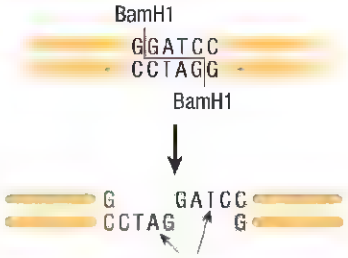


Figure 2 Restriction enzymes cut DNA molecules wherever they encounter a particular sequence of bases. In this case, BamH1 restriction enzyme cuts DNA at all GGATCC locations.

The use of plasmids and restriction enzymes led to modern recombinant DNA techniques. **Recombinant DNA** is a fragment of DNA made by combining nucleotide sequences that would not normally be present together in nature.

recombinant DNA a fragment of DNA consisting of nucleotide sequences from at least two different sources

Recombinant DNA can be made from any two pieces of DNA that have been cut with the same restriction enzyme. For example, if pieces of DNA from two different organisms are exposed to the restriction enzyme BamH1, they will both be cut into pieces ending with the same sticky ends—the four unpaired bases CTAG. Then pieces of DNA from each organism can be joined together by matching up these sticky ends. Geneticists can use this technique to transfer a piece of DNA with a gene of interest from one species into another.

Figure 3 provides a general overview of how bacteria can be used to engineer plants with new characteristics. The bacterium *Agrobacterium tumefaciens* is often used in the genetic engineering of plants.

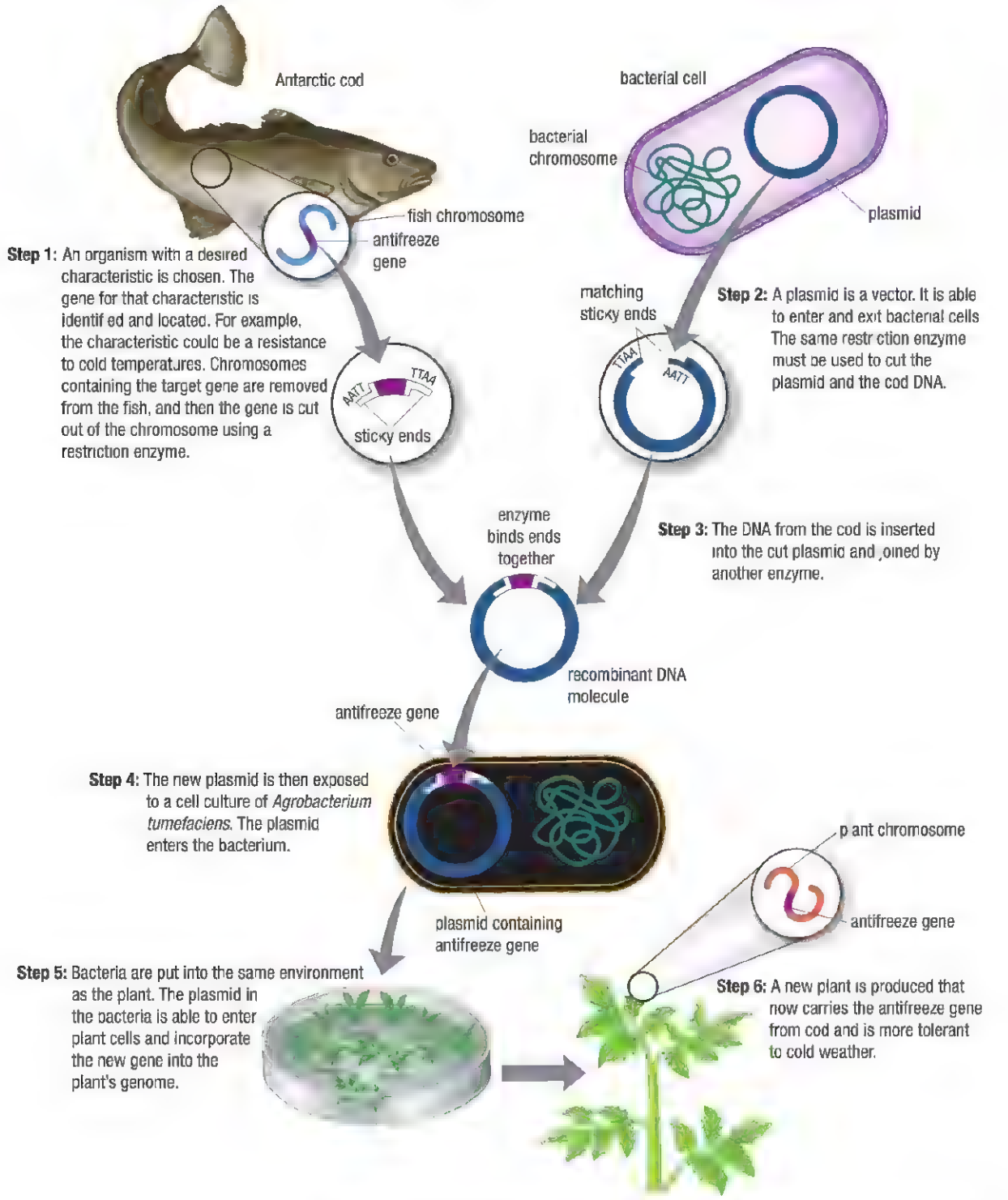


Figure 3 The antifreeze gene in cod is isolated and then inserted into the genome of a plant. The new plant will be able to tolerate lower temperatures.

Products of Genetic Engineering

There are many methods of genetic engineering. The method used depends on the origin of the gene to be inserted and where the genetic researcher wants to place it. However, no matter which method is used, many important products have been engineered for industry, medicine, and agriculture. Spider silk and Bt corn are two examples of products that have undergone genetic engineering. Spider silk is primarily used for research in the development of biomaterials, whereas Bt corn is produced commercially.

Spider Silk

Dragline fibre is the name given to the type of silk spiders use to build their webs. Scientists estimate that spider silk is at least five times as strong as steel and twice as strong as Kevlar—the material in bulletproof vests—of the same mass. It is also waterproof and ductile (stretchable). It stretches 30 % more than the most elastic nylon. Scientists hope to produce artificial fibres of a similar strength by studying the structure of spider silk to be used to manufacture such things as biomaterials for the aerospace industry, strings for tennis rackets, and airbags in vehicles (**Figure 4**).

Figure 4 (a) This female golden orb-weaver spider (Nephila sp.) produces silk in webs up to 2 m across! The silk produced by these spiders is amongst the strongest known, and their webs often catch small birds. Spider silk is, weight for weight stronger than steel. (b) This researcher holds a jar containing spider silk extracted from plants. Specific spider genes are inserted into plants, which then produce the proteins necessary to make spider silk. The mass-produced proteins and fibres can then be used in a number of applications.

Engineers are keenly interested in the strength of spider silk. Similar synthetic materials are not as strong. Because of the qualities of spider silk, biomaterials scientists are very interested in finding a way to produce large amounts of it.

Recombinant DNA technology has provided a way to make spider silk fibre outside a spider's body. The gene that produces the spider silk has already been isolated from spider cells and inserted into the genome of a goat! The goal is to create goats that produce spider silk protein in their milk. The silk would then be purified and used for the construction of new materials to be used in manufacturing, outerwear, parachutes, and other applications.

Bt Corn

Changes to the food industry have rarely been immediately welcomed. When milk was first pasteurized, it was greeted with suspicion, despite the fact that unpasteurized milk quite regularly causes illness and death, and that the new process eliminated many disease-causing microbes. Similarly, canned goods did not receive a warm welcome when they were first introduced, yet canned food is very common nowadays.

The latest revolution in food production is the use of recombinant DNA technology to make foods less susceptible to rotting, to enhance nutritional value, and to make crops resistant to pests and herbicides. In the past, farmers had these same objectives, but traditional methods required generations of trial and error to produce reliable seeds for plants with improved characteristics.

CAREER LINK

Biomaterials Engineer

Biomaterials engineers must have a good understanding of the properties of biomaterials. They try to design and build new products that mimic biological products. To learn more about a career as a biomaterials engineer,

GO TO NELSON SCIENCE

WEB LINK

To learn more about spider silk and how it is made outside of a spider's body,

GO TO NELSON SCIENCE

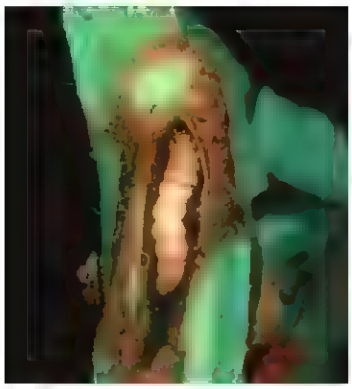


Figure 5 The European corn borer causes extensive damage to cornfields.

Bacillus thuringiensis (Bt) is a bacterium found in soil. Bt produces a natural pesticide of crystal proteins that are lethal to certain insects and their larvae but are harmless to humans. The genes for the crystal proteins have been inserted into a number of plants, such as corn, using recombinant DNA technology. As a result, the corn, now referred to as Bt corn, is able to produce its own pesticides against insects such as the European corn borer (**Figure 5**). Bt corn is a genetically modified (GM) food.

Using a pesticide in this manner is advantageous for several reasons. It reduces the need to spray crops with synthetic pesticides. Pesticides may be health hazards and produce runoff that contaminates lakes, rivers, and groundwater. Since farmers who grow Bt corn use fewer pesticides, their cost of production may go down depending on the added cost of the Bt corn seed. Yet there are concerns with producing a food product with a built-in natural pesticide. Some are worried that this new protein might cause an allergic response in certain people. If most farmers switch to this single GM variety, the genetic diversity of corn will be drastically lowered. Scientists and farmers are also concerned because they do not know what would happen if the Bt gene were ever to escape into wild plant populations.

6.4 Summary

- Genetic engineers can cut a gene from the genome of one organism and insert it into the genome of a different organism, where it is expressed.
- Restriction enzymes are chemical scissors that are able to cut out a gene fragment from a DNA source.
- Plasmids are circular pieces of DNA that are able to exit and enter bacteria cells and can be used to introduce new genes into an organism.
- Recombinant DNA technology uses plasmids and restriction enzymes to produce organisms with new characteristics.
- The agriculture, health, and manufacturing industries use recombinant DNA technology to increase disease resistance in crops and improve nutrition in foods.
- Recombinant DNA spider silk is a product that one day may be used in numerous applications as an alternative material.
- Bt corn has a gene that codes for a pesticide embedded within its genome. The use of Bt corn allows farmers to use less pesticides in cornfields.

6.4 Questions

1. What is recombinant DNA? Provide an example. K/U
2. Distinguish between restriction enzymes and plasmids. Why are they useful tools to have in a molecular biology lab? T/I
3. Construct a flowchart to describe the process by which a foreign gene is inserted into a genome. K/U C
4. Why are biomaterials engineers interested in being able to produce large amounts of spider silk? K/U T/I
5. What is Bt corn? Why would it be advantageous for a farmer to plant Bt corn rather than regular corn? T/I A
6. Make a list of pros and cons of using recombinant DNA technology in the food industry. T/I C A

Gene Therapy

6.5

On September 23, 2009, news headlines read "Historic Gene Therapy Trial to Treat Alzheimer's Disease." **Gene therapy** is a brand new experimental technique in which scientists try to overcome the negative effects of a defective gene by adding a normal gene, or try to repair the defective gene. The cells in which the gene needs to be replaced or repaired are known as **target cells**. In order to insert a normal gene into the genome, a specialized DNA sequence, called a **vector**, must be used to carry the gene into the target cells.

gene therapy the process by which defective genes in a genome are corrected with a normal copy of the gene

target cell one of the cells that contain the faulty gene to be corrected

vector any agent, such as a plasmid or a virus, capable of inserting a piece of foreign DNA into a cell

The Process of Gene Therapy

In Section 6.4 you read that plasmids, a type of vector, are used to carry genes into bacterial cells. Plasmids are useful, but they cannot be used in mammals. The vector of choice for mammals is a virus. Viruses are chosen depending on which type of target cells they need to enter. For example, a cold virus (**Figure 1**) would be a good choice to target lung cells, but not liver cells. The basic process of gene therapy is this:

1. Scientists remove or alter viral DNA so that the viruses cannot harm the cells they enter.
2. Copies of the DNA that include the normal human gene are placed inside each virus and are incorporated into the virus's own DNA.
3. Large numbers of these viruses are used to infect the target cells in an attempt to insert the normal human DNA into the cells' genome.

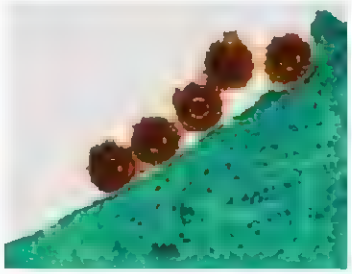


Figure 1 Viruses such as this adenovirus are good vectors for gene therapy. They are able to infect the target cell and transfer their DNA into the target cell. Normally, viruses insert their own DNA and force body cells to make more viruses. However, viruses can be tricked into helping the cells they invade cure themselves by introducing corrective DNA.

One limitation of this technique is that there is no way to control where the normal gene is inserted into the target cell's own genome. Recall that most of a genome is non-coding, so usually the inserted gene has no impact on the DNA around it. However, in rare cases the new gene might be inserted into a coding region, and this can disrupt the normal functioning of other important genes.

Does Gene Therapy Work?

Currently, gene therapy is still in the experimental stages, and no gene therapy product is available for sale. The progress of research has had both minor and major setbacks as well as successes.

Setbacks

In 1999 gene therapy experienced a huge setback when 18-year-old Jesse Gelsinger died. Jesse was being treated for ornithine transcarboxylase deficiency (OTCD). OTCD is a disease of the urinary system in which the body cannot get rid of ammonia. The ammonia builds up and causes liver damage, skin lesions, and developmental delay. Four days after starting the gene therapy treatment, Jesse's organs failed. Doctors believe that Jesse had an unexpected severe immune response to the virus. Recall that a virus delivers the normal gene. Your immune system is programmed to fight viruses. An immune response is expected and planned for, but in Jesse's case, the response was so severe that it led to his death.

In January 2003, gene therapy experienced another setback. A child who had taken part in a French gene therapy experimental trial developed leukemia. The leukemia appeared a few years after the gene therapy had been completed. Another child in the study had the same experience. Both children were being treated for severe combined immunodeficiency (SCID) syndrome, which is also known as "bubble baby" syndrome. Babies who have SCID are born with an underdeveloped immune system and usually die within their first year if exposed to viruses such as chicken pox. They are kept in isolation. In these cases, it seemed that the gene therapy activated another gene that causes leukemia, though scientists have not determined how that happened.

Gene therapy has several obstacles to overcome before it can become an effective treatment. These obstacles include the following:

- The normal gene inserted into the target cell must work for the duration of the target cell's life. Cells are constantly dividing because of mitosis. Therefore, many treatments of gene therapy may be required in order to ensure the normal gene becomes a permanent part of the target cell genome.
- It is not possible to control where a gene is inserted. If it is inserted in the middle of another gene sequence, it may disrupt the function of that gene and may result in more health challenges.
- The body's immune response must be constantly monitored because it is possible that the immune system will attack the foreign virus. Immunosuppressant drugs can be used, but they carry risks of their own.
- The virus may recover its ability to cause disease once it is in the target cell.
- Many disorders are caused by more than one gene. It is difficult to fix all the genes.
- Once the gene is transferred into the target cell, it needs to be regulated so that it is expressed at the required times. For example, a gene that regulates the production of insulin would need to be able to detect a low sugar level in the blood. If sugar levels are low, the gene that directs the production of insulin should not be turned on.
- The vector that is chosen must be able to reach all or most of the target cells specifically.

Successes

There are several examples of successful gene therapy. These include restoring vision in patients with an inherited retinal disease, repairing the gene that causes Duchenne muscular dystrophy, and restoring hearing after hairs in the inner ear are damaged.

INHERITED BLINDNESS

Veterinary vision scientists at the University of Pennsylvania have had success with gene therapy in dogs. The scientists have successfully transferred DNA to photoreceptors in the eyes of dogs to solve sight issues. Photoreceptors are cells in the retina that capture light and change it into an electrical signal that the brain can interpret. These cells were genetically defective in some dogs.

The success of this work is significant, because dogs are excellent model organisms for humans. Recall that model organisms have genomic characteristics similar to those of humans. Therefore, if a procedure works in a model organism, it is more likely to be safe to try in human trials.

In humans, a form of childhood blindness called Leber's congenital amaurosis (LCA) is the first inherited retinal disease for which gene therapy has been tested. Gene therapy has been performed on 12 patients, resulting in almost complete restoration of their vision. **Figure 2** outlines the experimental procedure.

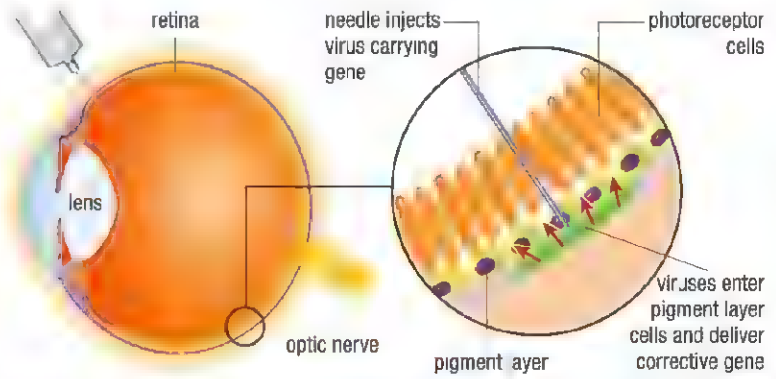


Figure 2 Gene therapy for Leber's congenital amaurosis (LCA). LCA is caused by a genetic defect in pigment layer cells on the retina. These cells are needed to support the photoreceptor cells.

1. An eye syringe is used to inject viruses carrying a normal gene behind the patient's pigment cell layer.
2. The viruses infect the pigment cells and deliver the normal gene.
3. The cells incorporate the normal gene, which restores normal functioning. This results in improved vision.

DUCHENNE MUSCULAR DYSTROPHY

Duchenne muscular dystrophy (DMD) is a severe recessive form of muscular dystrophy. It is sex linked, so it affects mostly males. People who suffer from DMD experience rapid muscle degeneration and have about one-third to one-half the usual life expectancy.

Researchers at Université Laval's Faculty of Medicine have successfully shown that it is possible to repair the gene responsible for DMD. A class of molecules known as meganucleases is able to repair the incorrect base-pair sequence in the faulty dystrophin gene. All the work thus far has been in mice, but it is possible that human trials will begin in two or three years. Considering all the research being done to find a cure for DMD, Muscular Dystrophy Canada believes that gene therapy holds the most hope thus far.

DEAFNESS

Sounds move tiny hairs in the cochlea of the inner ear. The hairs translate sound vibrations into nerve signals that are delivered to the brain. Normally, when hairs are damaged and hearing is lost, the change is permanent.

In 2005, a successful trial was conducted to restore hearing in guinea pigs. The guinea pigs had damaged hairs in their ears. A virus was used to deliver a gene that stimulated the growth of new hairs in the cochlea. Up to 80 % of the guinea pigs' ability to hear was restored! This is considered a hopeful new research direction.

6.5 Summary

- Gene therapy is an experimental technique used to possibly correct the effects of defective genes by inserting a normal gene into the genome or correcting the mistake in the gene sequence.
- There are several drawbacks to gene therapy: placement of the normal gene is random and cannot be controlled, an immune response could be triggered if a virus is used as a vector, and it is difficult to target disorders that result from mutations of multiple genes.
- Gene therapy has shown promise in the treatment of inherited blindness, Duchenne muscular dystrophy, and deafness.

6.5 Questions

1. Outline, using diagrams, the process of gene therapy. K/U
2. What characteristics enable viruses to be used as vectors in gene therapy? K/U
3. What are some of the challenges that scientists have to overcome in gene therapy? K/U A
4. Use the Internet and other sources to research a gene therapy success story or a gene therapy setback. Report your findings in two or three paragraphs. T/I C A
5. Make a list of ethical considerations for using gene therapy. Discuss your list with a classmate or group. T/I C A
6. Imagine that you are a member of the medical personnel on a starship colony of humans in the year 2112. Write a personal diary entry describing how gene therapy is used to treat your patients, who are affected by the disorders described in this section. K/U T/I C A

GO TO NELSON SCIENCE

6.6 Explore Applications in Genetics

SKILLS MENU

- Researching
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating
- Identifying Alternatives

Genetic Technology—The New Medicine

Genetic technology is on the leading edge of a revolution in medicine. Few things are more important than your health and the health of those you love. Healers and doctors from ancient to modern times have used many methods, both preventive and therapeutic, including prayer and meditation, nutrition and exercise, medications and vaccines, and more invasive procedures such as surgery and radiation therapy. Now, advances in our understanding of genetics and related genetic engineering technologies are providing entirely new tools for the diagnosis, treatment, and prevention of diseases.

There is a growing demand for advances in medicine. Society's concerns include our dependence on current pharmaceutical drugs and increasing antibiotic resistance among pathogens. Challenges also arise because of new diseases, an aging population, and our ongoing inability to effectively treat or prevent many serious diseases, including cancers and hereditary disorders. The healthcare industry is always striving to develop new technologies and new treatments for old diseases. Choices have to be made about government funds for more research into each new technology.

CAREER LINK

To learn more about becoming a registered healthcare lobbyist in Canada,

GO TO NELSON SCIENCE

The Application

You have been hired by a healthcare lobby group to conduct research on a proposed genetic technology. Depending on your research, the lobby group will decide whether they should push government to spend more money researching this genetic technology.

Your Goal

To research and assess some of the very latest healthcare applications of genetics in Canada and abroad, gain insights into the promises and challenges they offer, and present your findings and recommendations to the lobby group

WEB LINK

For more information about genetic technologies

GO TO NELSON SCIENCE

Research

Use the Internet and other resources to research one of the following current or next-generation genetic technologies and their applications. For each technology, complete the following:

- Use diagrams and/or a flowchart to describe how the technology works.
- Think about applications of the technology: What benefits does, or might, the technology provide? Consider applications in the diagnosis, treatment, and prevention of disease. Include specific examples.
- Understand the current status: Is the technology in use now? If so, describe its degree of success and/or failure.
- Summarize potential risks or limitations of the technology, and outline any ethical concerns.
- Consider the media status: What is the reputation of this technology so far? Is there any misinformation about this technology that is common in the news?

Decide whether the technology should receive funding for further research. Support your decision with facts and, if possible, quotes from leading scientists about the potential of this technology.

Some current and next-generation technologies are

- transgenic model organisms: the use of genetically modified organisms for medical research, including "knockout" technology
- gene therapy: the correcting of a genetic disorder by inserting a normal version of the defective gene (**Figure 1**)
- therapeutic cloning: the use of genetically modified tissues and organs for use in human patients
- animal and plant "pharming": the use of animals or plant crops for mass production of pharmaceutical products

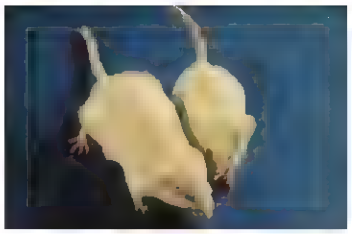


Figure 1 These mice are siblings that inherited a mutant dwarf condition. Scientists reversed the condition in the mouse on the left by using gene therapy to insert a copy of a rat growth-hormone gene into the embryo.

Summarize

After you have completed your research and assessed the current state of genetic engineering applications, especially in light of any Canadian contributions, compile a set of at least three to five recommendations for action. Complete the following sentence: Based on my research, I think you should/should not lobby for more research funding because . . .

Communicate

Communicate your findings to the healthcare lobby group that hired you. Your "Genetic Technology Brief" can be in the form of a written report, a slide show, a video, a computerized presentation or web page, or an oral presentation. Be creative, but obtain approval from your teacher about your plans before finalizing your project.

As part of your presentation to the members of the lobby group, who may not all have science backgrounds, include some information about how they can personally spot biased or unreliable research that they might see in the media. Currently, genetic technology is a popular topic in the media. Is everything that is reported true? Explain how members of the lobby group can determine this. Lobby groups may rely heavily on media reports instead of on primary reports on scientific findings. Why do you think that this might be? What can you suggest to the lobby group to minimize problems?

Plan for Action

In the past Canada has had challenges keeping talented scientists in the country to conduct their research. Many scientists leave the country due to lack of funding. They may be able to make more money elsewhere, or be able to get funding to obtain better equipment for a clinic to help others.

Find out who your local Member of Parliament (MP) and Member of the Provincial Parliament (MPP) are. Craft a letter that provides the MP and MPP with some background information about the genetic technology you researched. Include the contributions of some prominent Canadian geneticists, and hypothesize what more might be achieved within Canada if funding were available.

While you are writing, consider that the government officials may not have a science background. Present the information in manner appropriate for your audience. In your letter, you should provide reasons why research into this genetic technology should continue and why the government of Canada should provide more funds for research in this area.

GO TO NELSON SCIENCE

CHAPTER 6 Investigations

Investigation 6.3.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Comparing DNA Fingerprints

DNA fingerprinting is a molecular biology technique that can be used to compare two samples of DNA. If the banding patterns of the samples are the same, this is strong evidence that both samples of DNA came from the same person. In this investigation, you will use gel electrophoresis to compare the DNA fingerprints of two suspects to the DNA found at a crime scene.

Purpose

In this investigation you will determine, based on DNA fingerprint analysis, if a suspect's DNA matches the crime scene DNA.

Equipment and Materials

SKILLS HANDBOOK A1.2

- staining tray
- thermometer
- eye protection
- non-latex gloves
- balance
- 500 mL Erlenmeyer flask
- 250 mL graduated cylinder
- microwave or hot plate
- tongs or oven mitts
- gel electrophoresis chamber
- 10 µL micropipette and tips
- power supply (45 V)
- light box or overhead projector
- blank acetate sheet
- 1 g agarose
- 1 L 1× TBE buffer
- Eppendorf tube containing Suspect #1 DNA
- Eppendorf tube containing Suspect #2 DNA
- Eppendorf tube containing Crime Scene DNA
- plastic wrap
- 15 L loading dye (5 L × 3)
- 0.025 % methylene blue solution (enough to cover the gel in the staining tray)
- 70 % ethanol solution

Ethanol is flammable. Non-latex gloves and eye protection should be worn at all times. Wipe down the bench with ethanol upon completion of the laboratory exercise. Keep the DNA samples on ice until loading into wells.

Procedure

SKILLS HANDBOOK A2.4

Part A: Preparing the Gel

1. Measure out 0.96 g of agarose powder and transfer to a 500 mL Erlenmeyer flask.
2. Add 125 mL of TBE buffer to the flask and swirl to mix.
3. Heat the flask on a hot plate or in a microwave until the solution is completely clear. Use tongs or oven mitts to handle the flask.

Caution: If the agarose gel gets too hot it may bubble over. Be sure to observe your Erlenmeyer flask throughout the heating process. If the agarose solution starts to bubble up the neck of the flask, remove it immediately from the heat source with an oven mitt or tongs. Handle all hot glassware with caution.

4. Prepare the gel casting tray. Place a piece of tape across both ends of a casting tray. Be sure the tape is well sealed along the three edges of the tray end. Position the gel comb in the grooves of the casting tray. The comb will create wells in the agarose gel as the gel solidifies. (**Figure 1**).

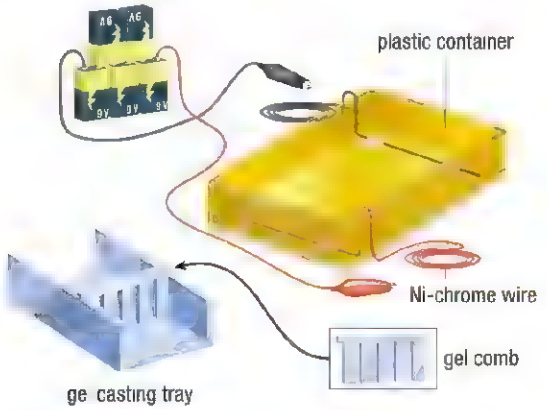


Figure 1 Homemade gel electrophores s chamber and casting tray

5. Once the agarose solution has cooled to about 50° C, pour the mixture into the gel casting tray. The comb teeth should be immersed in about 6 mm of agarose. The gel should cover only about one-third of the height of the comb teeth. Use a micropipette tip to pop any air bubbles in the gel as soon as it is poured.

6. Allow the agarose to set in the tray for at least 20 min. The gel will become cloudy as it solidifies. Do not disturb the gel as it solidifies.
7. Once the gel has set, carefully remove the tape from each end of the tray. Position the tray containing the gel in the gel electrophoresis chamber so that the end with the wells is closest to the negative electrode.
8. Cover the gel with TBE running buffer and then pull out the comb gently to avoid ripping any of the wells formed by the comb.
9. Add TBE buffer to the gel electrophoresis chamber until the buffer is approximately 5 mm above the gel. Place the gel electrophoresis chamber aside.

Part B: Loading the Gel

10. To each of the three Eppendorf tubes labelled Suspect #1, Suspect #2, and Crime Scene DNA, and using a new tip for each sample, add 5 µL of loading dye using the micropipette.
11. Tap the tubes on the lab bench to ensure mixing of the contents.
12. Again using a new tip for each sample, micropipette the full contents of each tube into a well on the gel. Be sure to record the order in which you dispense the tubes.
13. Cover the gel chamber and connect it to the power supply. Allow the gel to "run" for approximately 2.5 h. Be careful not to disturb or move the chamber while it works.
14. Unplug the power supply and carefully remove the gel. Wrap the gel in plastic wrap and place it in a refrigerator for a maximum of one day.

Part C: Staining the Gel

15. Unwrap the gel and place it in the staining tray.
16. Flood the gel with 0.025 % methylene blue solution. Let the gel sit in the solution for at least 25 min. Pour off the stain and flood with water. Pour off the water and replace it with new water. Repeat this process two to three times. Keep an eye on the intensity of the bands. If you stain for too long, you may lose some DNA fragments. If you do not destain long enough, the whole gel remains blue and the DNA fragments cannot be differentiated.
17. Place the destained gel on a light box or on an overhead projector.

Observations

18. Obtain a blank acetate sheet and place it over the gel. Trace the locations of the wells and the two suspects and crime scene banding patterns onto the sheet.

Analyze and Evaluate

(a) Compare the banding pattern of Suspects #1 and #2 to the Crime Scene DNA banding pattern. T/I

(b) Decide if either suspect's DNA matches the crime scene DNA. Explain your choice in detail. T/I

(c) The bands that have migrated the most are smaller fragments. Do some research and find out why smaller fragments travel farther. T/I

(d) DNA is negatively charged. Label your acetate sheet. Which end was toward the positive terminal? Which end was toward the negative terminal? How do you know? Use your knowledge of DNA structure from Section 6.1 to support your answer. T/I

(e) What is the purpose of the loading dye added to each sample of DNA? T/I

Apply and Extend

(f) What conclusions can you make with certainty about the DNA samples for Suspect #1, Suspect #2, and the crime scene? T/I

(g) Suppose you are a lawyer defending one of the suspects. Based on the DNA evidence that you found in this exercise, what arguments would you make? T/I C A

(h) List two ways in which you think you could improve this laboratory investigation. T/I A

CHAPTER 6 SUMMARY

Summary Questions

1. Look back at the Key Concepts listed at the beginning of the chapter, on page 226. Using a concept map with the word "DNA" in the middle, organize the main ideas and concepts presented in this chapter. Provide examples where appropriate. Use as many words from the vocabulary section below as possible.
2. Look back at the Starting Points questions at the beginning of the chapter, on page 226. Using specific examples from the chapter, answer the questions again. How do your answers differ? Identify three key pieces of information from this chapter that you feel are pertinent to your day-to-day life. Make a list of questions you would like to explore further from concepts and ideas presented in this chapter.

Vocabulary

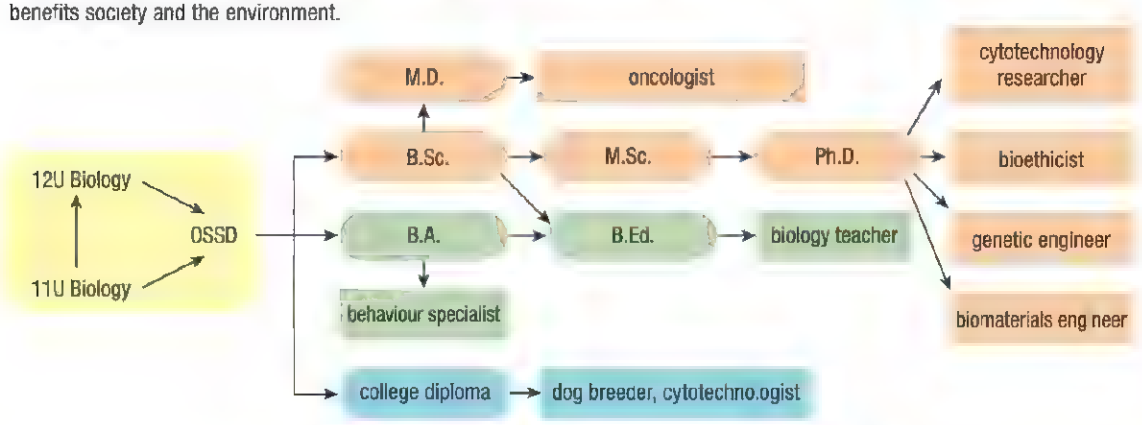
nuclein (p. 228)
nucleotide (p. 229)
X-ray crystallography (p. 230)
scientific model (p. 230)
complementary base pa ring (p. 231)
point mutation (p. 234)
chromosome mutation (p 234)
spontaneo.is mutat on (p. 236)
induced mutation (p. 236)
antibiot c resistant (p. 237)
transposon (p. 237)
transposition (p. 237)
microarray (p. 238)
Human Genome Project (HGP) (p. 240)
human genome (p 240)
coding DNA (p. 240)
non-coding DNA (p. 240)
functional genomics (p. 241)
model organism (p. 241)
DNA bank (p. 242)
DNA fingerprinting (p. 243)
restriction enzyme (p. 245)
recombinant DNA (p 245)
gene therapy (p. 249)
target cel (p. 249)
vector (p. 249)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college dip oma or a B.Sc. degree. Others require specialized or postgraduate degrees. This grapnic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select two careers related to genetic processes that yoJ find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



GO TO NELSON SCIENCE

CHAPTER 6 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which best describes the structure of human DNA? (6.1) K/U
   (a) two parallel, identical strands of nucleotides
   (b) two strands of nucleotides that intertwine in opposite directions to form a corkscrew pattern
   (c) two identical copies of a chain of nucleotides linked to form a single, long strand
   (d) circular, interconnected chains of nucleotides
2. Which molecule would form a complementary bond with a cytosine molecule in DNA? (6.1) K/U
   (a) another cytosine molecule
   (b) an adenine molecule
   (c) a guanine molecule
   (d) a thymine molecule
3. Which mutation would be classified as induced? (6.2) K/U
   (a) crossing over during meiosis
   (b) a copying error during chromosome replication
   (c) a non-disjunction error during meiosis
   (d) a gene permanently damaged by the chemicals in cigarette smoke
4. Which disease or disorder shows how mutations can be both beneficial and harmful? (6.2) K/U
   (a) Down syndrome
   (b) cystic fibrosis
   (c) muscular dystrophy
   (d) sickle-cell anemia
5. In which situation is DNA fingerprinting most commonly used? (6.3) K/U
   (a) providing forensic evidence in criminal cases
   (b) providing evidence in paternity suits
   (c) identifying unknown remains
   (d) establishing ancestral lines
6. A genetically engineered organism was created to produce a desired product. Consider the possible events below (given in no particular order).
   (i) foreign gene and plasmid combined
   (ii) foreign gene–produced product
   (iii) DNA cuts made with restriction enzymes
   (iv) recombinant plasmid taken up by a bacterium
   Which is their most likely sequence? (6.4) T/I A
   (a) iii, ii, iv, i
   (b) i, iii, iv, ii
   (c) iii, i, iv, ii
   (d) ii, i, iv, iii
7. Which statement is true of viruses used to introduce genes into human cells? (6.5) K/U
   (a) They must be altered so they do not cause disease.
   (b) They are never attacked by the host's immune system.
   (c) They always insert genes precisely in the same place.
   (d) They only succeed when they contain plasmids.
8. Which description best characterizes the current state of gene therapy? (6.5) T/I
   (a) relatively new; some successes and some failures
   (b) well established; used in many treatments
   (c) not considered to have much potential
   (d) no successes yet; only failures

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

9. Of the possible point mutations, base-pair substitution is likely to have the smallest impact on the assembly of proteins by ribosomes. (6.2) T/I
10. A mutation can be inherited if it occurs in a somatic cell. (6.2) K/U
11. Barbara McClintock experimented with mutations in corn caused by ultraviolet radiation. (6.2) K/U
12. An infection that does not respond to antibiotics is likely caused by a resistant virus. (6.2) A
13. The nucleotide sequence ATCGGGTAT would be complementary to TAGCCCATA. (6.2) T/I
14. The human genome consists of about 3 million base pairs. (6.3) K/U
15. Mice are a good genetic model for humans. (6.3) K/U
16. The greatest proportion of DNA in humans is coding (6.3) K/U
17. The BamH1 restriction enzyme would be able to cut the segment of DNA shown here: (6.4) T/I

    AATGGATCTACC
    TTACCTAGATGG

18. Bt corn is genetically engineered to make its own herbicide. (6.4) K/U
19. *Agrobacterium tumefaciens* is often used to insert genes into plants. (6.4) K/U

To do an online self-quiz, GO TO NELSON SCIENCE

CHAPTER 6 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. If analysis of the double-stranded DNA in an organism reveals that 30 % of the nitrogenous bases are adenine, which statement is true? (6.1) T/I
   (a) 15 % must be thymine.
   (b) The combined percentage of adenine and thymine must be 60 %.
   (c) 30 % must be guanine.
   (d) The combined percentage of guanine and cytosine must be 60 %.
2. On which part of a DNA molecule does the negative charge reside? (6.1) K/U
   (a) phosphate groups
   (b) sugar molecules
   (c) nitrogenous bases
   (d) all of the above
3. Which describes the possible effect of a genetic mutation? (6.2) K/U
   (a) harmful
   (b) beneficial
   (c) neutral
   (d) any of the above
4. What is the term for a chromosomal mutation in which gametes inherit too many or too few chromosomes? (6.2) K/U
   (a) translocation
   (b) non-disjunction
   (c) frameshift defect
   (d) autosomal error
5. Which of the following is another name for a transposon? (6.2) K/U
   (a) regulator gene
   (b) jumping gene
   (c) promoter gene
   (d) frameshift gene
6. About how many genes are there in the human genome? (6.3) K/U
   (a) 200
   (b) 2000
   (c) 20 000
   (d) 200 000
7. Which of the following is the preferred term for "junk" DNA? (6.3) K/U
   (a) mutated DNA
   (b) transposed DNA
   (c) interpolated DNA
   (d) non-coding DNA
8. Which term describes the role of plasmids in genetic engineering? (6.4) K/U
   (a) vector
   (b) transposon
   (c) mutagen
   (d) chemical scissors
9. Which function was restored in guinea pigs, using experimental gene therapy in 2005? (6.5) K/U
   (a) hearing
   (b) vision
   (c) muscular coordination
   (d) red blood cell count

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

10. The component of nucleotides that contains nitrogen is deoxyribose. (6.1) K/U
11. If a scientist wished to determine the pattern in which the atoms of a pure substance are arranged, he might use microarray technology. (6.1, 6.2) K/U
12. Damage to a cell's DNA caused by ultraviolet radiation could cause a spontaneous mutation. (6.2) K/U
13. Antibiotics were discovered when mould was observed to kill bacteria in laboratory cultures. (6.2) K/U
14. The National DNA Data Bank in Canada stores the DNA of endangered species. (6.3) K/U
15. Recombinant DNA is created by connecting nucleotide sequences that would never be found together in nature. (6.4) K/U
16. Bt corn is genetically engineered to be more drought resistant than normal corn. (6.4) K/U
17. Muscular Dystrophy Canada believes that stem cell treatment holds the most promise for curing Duchenne muscular dystrophy. (6.5) K/U
18. **Figure 1** (next page) shows a diagram of a single DNA strand. Match the terms below to the labels in the diagram. (6.1) K/U
    (a) phosphate group
    (b) pentose sugar molecule
    (c) thymine
    (d) guanine
    (e) adenine
    (f) cytosine

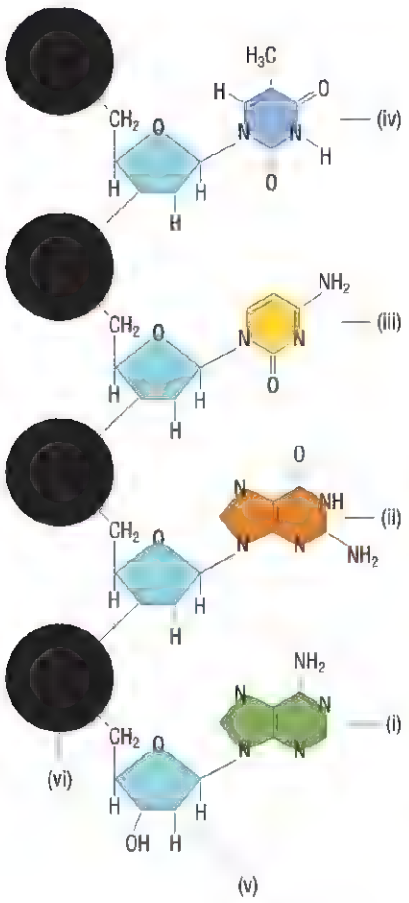


Figure 1

Match the scientist(s) on the left with the most appropriate discovery or theory on the right.

19.

(a) Alfred Hershey and Martha Chase	(i) A material in the nuclei of algae cells directs regeneration.
(b) James Watson and Francis Crick	(ii) Nuclein (now called DNA) is present in cell nuclei.
(c) Rosalind Franklin and Maurice Wilkins	(iii) Viral DNA alone can make bacteria produce new viruses.
(d) Phoebus Levene	(iv) DNA is a double helix held together by weak forces between bases.
(e) Joachim Hammerling	(v) DNA has three main chemical components.
(f) Friedrich Miescher	(vi) DNA has a helical structure. (6.1) K/U

Write a short answer to each question.

20. DNA is composed of many similar units linked together in strands. What are these units? (6.1) K/U
21. Under what circumstances can a mutation be passed from a parent to an offspring? (6.2) K/U
22. What is the name given to the branch of genetics that focuses on gathering information about genes and their functions? (6.3) K/U
23. To what organism does the largest genome sequenced so far belong? (6.3) K/U
24. A plasmid into which a foreign gene has been spliced is classified as what type of DNA? (6.4) K/U

Understanding

25. What is related to a gene in the same way that a typographical error is related to a document? (6.2) K/U
26. If an *Acetabularia* cell (**Figure 2**) is cut in half, which part—the cap or the foot—can regenerate into a new cell? Why? (6.1) K/U

Figure 2

27. Distinguish between the terms "nucleotide" and "nitrogenous base." (6.1) K/U
28. Is a genetic mutation always accompanied by a change in phenotype? Explain your answer. (6.2) K/U
29. In each case, state what kind of mutation has occurred if the original base sequence was TATACGGTA. (6.2) K/U T/I
    (a) TATCGGTA . . .
    (b) TATACGGATA . . .
    (c) TATATGGTA . . .
30. Distinguish between chromosomal mutations and point mutations. (6.2) K/U
31. What does sickle-cell anemia demonstrate about the possible effects of a mutation? (6.2) K/U
32. Would you describe DNA as an unstable molecule or a stable molecule? Explain your thinking. (6.3) T/I
33. Describe three uses for DNA fingerprinting other than for criminal investigations. (6.3) K/U
34. How does the number of base sequences in small mammals compare to the number of base sequences in large mammals? (6.3) K/U

35. What are the "sticky ends" that result when restriction enzymes cut DNA? (6.4) K/U
36. What makes plasmids useful in genetic engineering? (6.4) K/U
37. Why are scientists so interested in producing artificial spider silk through genetic engineering? (6.4) K/U
38 Distinguish between genetic engineering and gene therapy. (6.5, 6.6) K/U

Analysis and Application

39. Draw an analogy between the structure of DNA and the structure of a ladder. Use the following terms in your answer: phosphate groups, pentose sugar molecules, nitrogenous bases. (6.1) T/I C A
40. The DNA in a bacterium may be 1000 times longer than the bacterium itself. Offer ideas to explain how so much DNA could fit inside a bacterial cell. (6.1) T/I C
41. What did Erwin Chargaff discover about DNA in 1940? Explain why this discovery provides evidence that DNA has complementary base pairing. (6.1) C A
42. A researcher has prepared an extract from cells and wants to capture single stranded DNA fragments that have the base sequence TACGCATGGAAT. What DNA strand could she synthesize and attach to a microarray to act as a "trap" for the target DNA? Explain your thinking. (6.1, 6.2) C A
43. Consider a DNA strand with the base sequence TACGAGCAGGCCTACGAGCAATACCAG. In how many places could a shorter DNA strand ATGCTC attach completely through complementary bonding? Draw a diagram showing each possibility. (6.1) T/I C
44 A small section of one of the strands in a double-helix DNA is destroyed by a chemical agent. If the corresponding section of the other strand has a base sequence of ATGCGCTAT, what must the base sequence have been in the damaged section? How do you know? (6.2) K/U C
45. In each case, state if the mutation can cause a genetic disease to appear in an individual. Also state in which successive generation, if any, the disease can appear at the earliest. Explain your thinking. (6.2) T/I C A
    (a) a dominant mutation occurring in an autosome of somatic (body) cells
    (b) a dominant mutation occurring in an autosome of sex cells (gametes)
    (c) a recessive mutation occurring in an autosome of sex cells (gametes)
46. How would the number of adults with lactose intolerance in the world be different if all human populations had consumed milk from domesticated animals throughout human history? Explain your reasoning. (6.2) C A
47 In the past, antibiotics were often prescribed for mild illnesses that, in time, would likely go away on their own. Antibiotics were also prescribed for viral illnesses (which do not respond to antibiotics) to reduce the risk of a bacterial infection developing. The medical community currently discourages these practices. Why would the medical community adopt this position? (6.2) T/I C A
48. What advantage would a rapid spontaneous mutation rate give bacteria when they are exposed to antibiotics? (6.2) C A
49. Tanning beds bathe the user in ultraviolet light to produce an artificial suntan (**Figure 3**). What danger might tanning beds pose? Use the term "mutation" in your answer. (6.2) K/U A

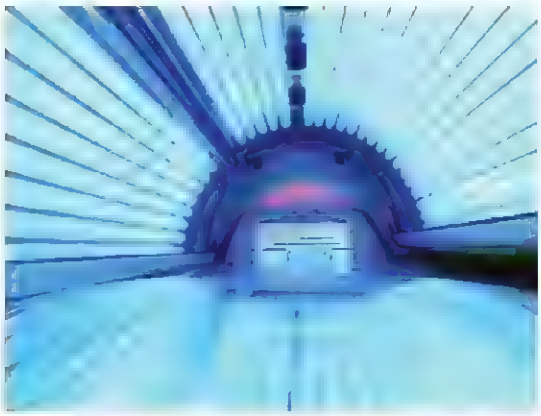


Figure 3

50. The number of base pairs in the human genome is about 150 000 times greater than the number of genes. This does not mean, though, that human genes average about 150 000 base pairs each. Explain why. (6.3) T/I C
51. Examine the DNA fingerprints shown in **Figure 4**. (6.3) K/U T/I C
    (a) Why would the profiles of the technician and the victim be included?
    (b) Based on the evidence, what can you say about the guilt or innocence of the two suspects? Defend your answer.

Figure 4

52. Offer and explain three reasons why scientists would elect to use an animal model in studying human genetics. (6.3) T/I C A

53. A large number of identical strands of 42-base-pair DNA are cut by a restriction enzyme whose cutting sequence is shown in **Figure 5**. The cuts produce many copies of the following three DNA fragments, whose base sequences are shown:

Fragment 1
TATACACT
GTGA

Fragment 2
TACTGCCAGTATGATG
ATGACGGTCATACTACATAT

Fragment 3
TATACACGTGCCAGTATG
GTGCACGGTCATACATAT

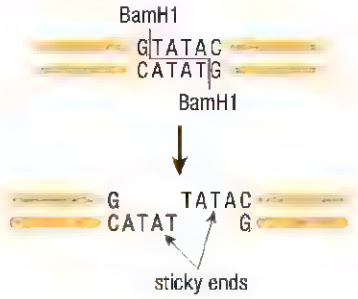


Figure 5

(a) From the structure of the DNA fragments, deduce what the base sequence in the original DNA strands must have been, and write it out.
(b) In how many places was the original strand cut? How can you tell? (6.4) T/I C A

54. Explain why the same restriction enzyme must be used to cut the source DNA and the plasmid DNA when a foreign gene is to be inserted into a bacterium. (6.4) K/U C A

55. Genetically engineering crop plants to be insect resistant was described in this chapter. List three other traits a genetic engineer might want to introduce into crop plants. In each case, explain why the trait would be desirable. (6.4) C A

56. A strain of laboratory mice has been bred to have a disorder that is hypothesized to result from a defective gene. A researcher uses a virus to introduce a normal copy of the gene into target cells in the mice, but the mice show no improvement. Assuming the vector was effective, what might account for the failure of the attempted therapy? (6.5) T/I A

57. Why is a virus a good vector for inserting genes into the DNA of humans and other mammals? (6.5, 6.6) K/U

58. In an experiment, an animal with a genetic disorder is given gene therapy treatment. For a time, the animal's condition improves, but then a relapse occurs. (6.5) T/I

(a) What has most likely happened?
(b) What must be done to make the improvements in the animal's condition long lasting?

59. State and describe three ways in which an attempted gene therapy using a virus vector could create even worse health problems (6.5, 6.6) K/U T/I

60. In 1997, scientists at the Lawrence Berkeley National Laboratory announced that they had genetically engineered a strain of mice whose only active hemoglobin genes were human sickle-cell genes. (6.2, 6.5, 6.6) T/I C A

(a) Why would this strain of mice be very useful for medical researchers?
(b) Simply treating normal mice with a vector carrying the human gene for sickle-cell disease, a recessive gene, was not successful in producing mice that developed all of the symptoms of sickle-cell disease. What other genetic challenge must the researchers have solved?

Evaluation

61. How does the discovery of the structure of DNA illustrate the importance of communication and collaboration in science? (6.1) K/U C A

62. Describe at the molecular level how a mutation in a gene causes changes in a cell. Include the term "proteins" in your answer. (6.2) K/U C A

63. Explain how microarrays are an example of the benefits that technology can bring to our lives. (6.2) K/U C

64. A fellow student proposes that the degree to which an organism is regarded as a "higher organism" is directly related to the size of the organism's genome. Do you agree? Why or why not? (6.3) K/U C A

65. **Figure 6** shows a section of gene DNA with the nucleotides grouped according to how they will be read by ribosomes in assembling a protein. (6.2) T/I C

Figure 6

(a) Write three modified versions of this DNA sequence that illustrate, respectively, the three major point mutations. In each case, create a single mutation at the arrowed location. Label each drawing with the specific type of mutation it illustrates, and group the nucleotides from left to right into threes, as in the original.

(b) Based on your drawings, evaluate the impact of the mutations on the protein that the ribosomes will assemble from the nucleotide code. Which mutations have the potential to produce the greatest negative consequences? Why?

66. For what reasons do you believe that in the Human Genome Project, the researchers were not allowed to know the identities of the DNA donors and the donors were not told whose samples were actually analyzed? (6.3) T/I C

67. Hypothesize as to why coding DNA is much more similar from person to person than non-coding DNA. Explain your reasoning. (6.3) T/I C

68. At a pharmaceutical company, chemicals are added to rupture *E. coli* cells in a batch of culture medium, and through centrifugation and filtration, human insulin is collected for use as a medicine. Explain how genetic engineering makes this possible. (6.4) K/U C A

69. A genetic engineer has prepared a virus for use as a vector in experimental human gene therapy. You are a hospital official who must decide if the virus poses any significant risks to the subjects who will receive it. What evidence would you ask the genetic engineer to provide as you make your decision? (6.5) T/I C A

70. It is possible that "junk" DNA performs important, genetic functions in cells that have not been discovered yet. What concerns might this raise about inserting a gene into human DNA as a part of a gene therapy or other experiment? (6.5) T/I C A

Reflect on Your Learning

71. What concerns do you have about how DNA analysis may one day threaten your rights to privacy? Give examples as a part of your response. T/I C A

72. Think about how the parts of your body compare to those of a gorilla or a chimpanzee (**Figure 7**). What are the similarities and differences? How is this comparison related to a comparison of the human genome and the genomes of apes and chimps? K/U C A

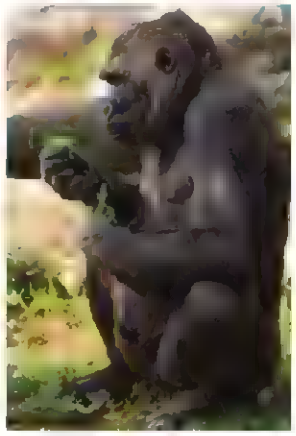


Figure 7 Female gorilla

73. Genetic screening can reveal whether or not someone has a serious disease that will likely develop later in life. Would you volunteer for such testing to "know your future"? Why or why not? C A

74. Genetically engineered foods are now beginning to enter the marketplace. In your opinion, is reluctance toward accepting genetically engineered foods wise or unfounded? Why do you think so? C A

75. Of the examples of genetic engineering and gene therapy you have studied in this chapter, which did you find most interesting? Explain why. K/U C

76. Suppose you are a philanthropist who wants to donate a great deal of money to a worthy cause. Would you give money to organizations that are attempting to reduce world hunger or to research programs that are trying to develop gene therapies? What is the reasoning behind your choice? C A

77. Some people think that genetic engineering may one day be used to build perfect humans "from scratch." Would you support scientific efforts to make genetically perfect humans? Explain your thinking. C A

Research

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78. Experiments by a team of scientists led by Oswald Avery in 1944 provided important information about DNA (**Figure 8**, next page). Research the work of these scientists and prepare a poster with flowcharts and illustrations that describes their experiments and their conclusions. T/I C A

Figure 8

79. Research how a type of chemical attraction called hydrogen bonding is responsible for the complementary base pairing that holds the strands together in double-helix DNA. Present your findings in a report that includes diagrams or is accompanied by molecular models. T/I C A

80. Find out how Alfred Hershey and Martha Chase used radioactive markers in their studies of the hereditary material in bacterial viruses. Present your findings in the form of a clearly labelled flowchart or diagram. K U

81. "Molecular clocks" use genetic comparisons to establish evolutionary timelines. Find out how molecular clocks work. Write a report of your findings that includes an example of the type of conclusions that can be drawn from molecular clock evidence. T/I C A

82. Research why computers played an important role in the approach Celera Genomics took in sequencing the human genome, especially with regard to "shotgun sequencing." Write a brief report that details what you find and includes supporting diagrams. T/I C A

83. There is considerable scientific interest in determining whether or not "junk" DNA performs important genetic functions. Research and report what scientists have discovered up to the present. C A

84. Using genetic engineering, scientists have made plants that glow in the dark much like fireflies. Find out how this was accomplished and what the practical uses of such studies are or may be. Prepare an oral presentation that includes diagrams and sample images. T/I C A

85. DNA fingerprinting has been significant in law enforcement (**Figure 9**). Conduct research to find some Canadian examples of criminal trials in which DNA fingerprinting has been submitted as evidence. T/I A
    (a) How did the DNA fingerprint evidence affect the trial?
    (b) Do you think DNA fingerprinting should ever be used to convict a criminal? Explain your reasoning.

86. Use the Internet and other sources to research the genetic technologies described in this chapter. T/I A
    (a) Which technology did you choose to research, and why?
    (b) Prepare a short report about your topic, synthesizing the information you learned. Include in your report an analysis of the advantages and disadvantages of the technology, both scientific and social.

Figure 9 Analysis of DNA fingerprints. The pattern of DNA bands produced by DNA fingerprinting is unique to each individual, but some bands are shared by related people, such as a parent and child. DNA fingerprints can be used to prove conclusively whether people are related, for instance, in cases of disputed paternity, or where immigrants to a country need to prove a family relationsh p.

UNIT 2 UNIT TASK

Assessing a Genetic Concern

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

There are many heritable human genetic disorders. Their effects range from mild to severe. To reduce the negative consequences of such a disorder, it is critical that scientists understand the pattern of inheritance, its precise genetic cause, and options for treatment. It is equally important that such scientific understanding be shared with the individuals and families involved (**Figure 1**).

In this Unit Task you will investigate the medical case history of an individual with a concern about a genetic disorder. After considering the circumstances of the individual and his or her family medical history, you will conduct research to identify the disorder and describe its characteristics in a written report.

Figure 1

Purpose

You will investigate the case history of an individual with concerns regarding a genetic disorder, identify the disorder, and research its characteristics and current options for treatment.

Equipment and Materials

- patient medical case history file (refer to page 265 for an example; your teacher may provide you with a different case history file)

Procedure

Part A: Inheritance and Diagnosis

1. Obtain a case history file from your teacher. The file contains information on the family history of the individual of concern as well as his or her medical background and current symptoms. Use the case history to complete Steps 2 to 4.
2. Examine the family pedigree chart for the genetic disorder.
3. Determine how the genetic disorder is inherited. For example, is it autosomal recessive or dominant, or is it a sex linked trait?
4. Use the case history file and your answer from Step 3 to research the genetic disorder. Use your research to identify the genetic disorder to the best of your ability.
5. Verify your conclusions with your teacher before proceeding to Part B.

Part B: Genetics and Pathology

6. Use the Internet and other sources to research what is known about the specific genetic cause of the disorder. Look for information to answer the following:
   (a) What specific gene is responsible for this disorder?
   (b) On what chromosome is the gene located?
   (c) What is the function of the gene? What protein does it normally code for?
7. Research the effects of the genetic disorder. How does the genetic disorder influence the health of the individual? If possible, explain how the disorder accounts for the known symptoms.

Part C: Treatment

8. Research current options for treatment. Note any benefits and risks involved in these methods.

Part D: Medical Report

9. Prepare a report that summarizes your findings from Parts A, B, and C. The report should be written in a form suitable for sharing with the affected individual and family members.

   Consider what is the best way to present the information. Use of a family pedigree chart, for example, might help explain the inheritance pattern of the disorder.

Patient Medical Case History File #11U01A

Personal Data

Sex: female
Age: 32

Patient's Initial Concern

The young female recently contacted the health clinic regarding her concern about a potential genetic condition in her family. The patient and her spouse are planning on having their first child. They have requested a consultation with a geneticist to find out more about the possible implications of the patient's family history. The patient's spouse has a family history with no similar health problems.

Medical History Provided by the Patient and Family

The patient feels she is in good health. She is physically very active and eats a healthy diet.

The patient is most concerned because her older brother has started to have a few health issues that reminded her of those of her late uncle (**Figure 2**). The patient's brother has recently been tested for diabetes and seems to be showing early signs of skin pigmentation. His skin has a "bronze" appearance.

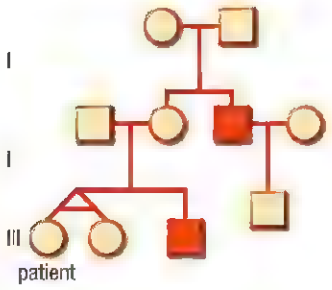

Figure 2

The patient's uncle is no longer living. He died in a car accident at age 52 but had started to have significant health problems in his mid-forties. Although he was never formally diagnosed with a genetic disorder, he had developed diabetes and had a number of other symptoms. He regularly complained of joint pain, fatigue, and a general lack of energy, and had experienced some degree of hearing loss. His skin was unusually "bronze" in colour—as if he had developed a permanent tan. Although the patient's uncle consumed very little alcohol, the patient recalled that a doctor friend had suggested he be tested for cirrhosis of the liver.

Results of Medical Exam and Consultation

Patient: The medical exam and test results indicate that she is a perfectly healthy individual.

Patient's brother: The test results indicate he has diabetes but otherwise seems quite healthy. The most unusual finding was his very high blood iron content. On questioning, he mentioned that he has noticed some early signs of arthritis, with joint stiffness and mild discomfort.

Additional Comments

Family members recall that the patient's grandmother had developed arthritis and diabetes shortly after menopause.

ASSESSMENT CHECKLIST

Your completed Unit Task will be assessed using the following criteria:

Knowledge/Understanding

- ✓ your ability to construct and interpret a pedigree chart
- ✓ your ability to recognize the pattern of inheritance of a genetic disorder
- ✓ your ability to understand the relationship between a mutated gene and an inherited disorder

Thinking/Investigation

- ✓ your ability to use information provided on the symptoms of a disorder to research a probable diagnosis
- ✓ your ability to synthesize information from a variety of sources
- ✓ your ability to consider and evaluate a number of options, based on the accuracy and currency of information from various sources

Communication

- ✓ the organization and clarity of the information in your consultation report
- ✓ the effectiveness of your written presentation

Application

- ✓ the quality of your assessment of the options available to the individual and family
- ✓ your ability to identify and describe genetic disorders, in terms of physical effects and treatments

UNIT 2 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which of the following physical traits represents a potential cost of sexual reproduction? (4.1) K/U
   (a) a striped coat that enables camouflage
   (b) great speed
   (c) brightly coloured feathers that could alert predators
   (d) acute night vision
2. How many chromosomes do normal human body cells contain? (4.1) K/U
   (a) 23
   (b) 24
   (c) 46
   (d) 92
3. Asexual reproduction is rare among which of the following groups? (4.2) K/U
   (a) unicellular organisms
   (b) plants and fungi
   (c) invertebrates
   (d) vertebrates
4. Which of the following stages of mitosis is shown in **Figure 1**? (4.2) K/U
   (a) prophase
   (b) metaphase
   (c) anaphase
   (d) telophase

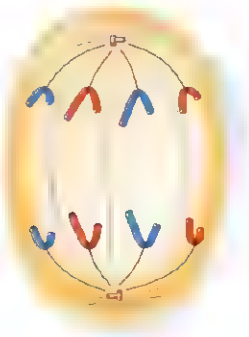

Figure 1

5. Which of the following methods of reproduction results in offspring that are genetically different from a parent? (4.2, 4.3) K/U
   (a) budding
   (b) fragmentation
   (c) sexual reproduction
   (d) all of the above
6. In humans, spermatogenesis begins with a somatic cell that has 46 chromosomes. When spermatogenesis is complete, how many sperm cells will be formed and how many chromosomes will each sperm cell contain? (4.3) K/U
   (a) 4 sperm cells each containing 23 chromosomes
   (b) 2 sperm cells each containing 46 chromosomes
   (c) 4 sperm cells each containing 46 chromosomes
   (d) 2 sperm cells each containing 23 chromosomes
7. During meiosis I, chromosomes exchange genetic information, a process known as
   (a) independent assortment
   (b) oogenesis
   (c) crossing over
   (d) interphase (4.3) K/U
8. Sex cells are called
   (a) autosomes
   (b) monosomes
   (c) trisomes
   (d) gametes (4.3) K/U
9. Chromosomes that are not sex chromosomes are called
   (a) autosomes
   (b) monosomes
   (c) trisomes
   (d) gametes (4.3) K/U
10. Down syndrome occurs because of
    (a) a meiosis error
    (b) non-disjunction
    (c) trisomy
    (d) all of the above (4.4) K/U
11. A zygote's inheritance of cytoplasmic DNA from the female gamete as a result of sexual reproduction is called
    (a) maternal inheritance
    (b) paternal inheritance
    (c) trisomy
    (d) horizontal gene transfer (4.5) K/U
12. Mendel's pea plants were useful for his experiments because for many characteristics, such as seed shape, flower colour, and plant height, they exhibited complete dominance and had only two
    (a) chromosomes
    (b) alleles
    (c) genes
    (d) genotypes (5.1, 5.2) K/U

13. Human blood type AB is a trait that results from both codominance and
    (a) incomplete dominance
    (b) a polygenic trait
    (c) a single allele
    (d) multiple alleles (5.2) K/U
14. Dr. Nancy Wexler studied family histories and pedigrees of Lake Maracaibo villagers to better understand their high incidence of
    (a) cystic fibrosis
    (b) Down syndrome
    (c) breast cancer
    (d) Huntington's disease (5.4) K/U
15. Guanine, thymine, adenine, and cytosine are
    (a) phosphate groups
    (b) nitrogenous bases
    (c) sugars
    (d) none of the above (6.1) K/U
16. Approximately how many base pairs make up the human genome? (6.3) K/U
    (a) 300
    (b) 3000
    (c) 3 000 000
    (d) 3 000 000 000
17. Organisms that contain genes from other organisms are considered
    (a) transgenic
    (b) mutated
    (c) cloned
    (d) hybridized (6.4) K/U
18. Molecules that have the ability to cut DNA at a specific site are called
    (a) transgenes
    (b) restriction enzymes
    (c) recombinant DNA
    (d) mutations (6.4) K/U
19. The process by which a defective gene is replaced in order to correct a genetic disorder is called
    (a) mutation
    (b) hybridization
    (c) complementary base pairing
    (d) gene therapy (6.5) K/U
20. In gene therapy, the cells containing the gene that needs to be replaced are called
    (a) plasmids
    (b) transgenes
    (c) target cells
    (d) restriction enzymes (6.5) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

21. Ribonucleic acid, or DNA, is the genetic material that is carried in a chromosome. (4.1) K/U
22. The genes for a specific characteristic can be found at various locations on a chromosome. (4.1) K/U
23. Organisms that reproduce asexually inherit half their genetic information from one parent. (4.1) K/U
24. Mitotic cell division results in two daughter cells that are genetically identical to each other and to the parent cell. (4.2) K/U
25. Cloned populations are more susceptible to certain diseases because of their lack of genetic variability. (4.2) K/U
26. Homologous chromosomes are assorted independently of other chromosomal pairs. (4.3) K/U
27. Gametogenesis produces sex cells with half the number of chromosomes as a body cell. (4.3) K/U
28. When homologous chromosomes fail to separate during meiosis, non-disjunction occurs. (4.4) K/U
29. Plants that, when self-pollinated, always produce offspring with the same trait are called hybrids. (5.1) K/U
30. An organism with two identical alleles for a trait is said to be homozygous for that trait. (5.1) K/U
31. A Punnett square is a chart that tracks the inheritance of a trait through a family. (5.2) K/U
32. An organism whose phenotype is a blend of different traits exhibits codominance. (5.2) K/U
33. Among sex-linked genetic disorders, X-linked disorders are less common than Y linked disorders. (5.3) K/U
34. Genetic screening is the test for a mutated gene. (5.5) K/U
35. Because of complementary base pairing, if you know the base sequence of one strand of DNA, you cannot predict the sequence of the other strand. (6.1) K/U
36. Mutations always have negative effects on the phenotype of an individual. (6.2) K/U
37. The human genome contains about 20 000 genes. (6.3) K/U
38. Gene therapy has very few drawbacks. (6.5) K/U

To do an online self-quiz,
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UNIT 2 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. Which of the following processes increases diversity in a population? (4.1, 4.2) K/U
   (a) sexual reproduction
   (b) asexual reproduction
   (c) cell division
   (d) fragmentation
2. Prior to cell division, the original chromosome and the duplicate it is attached to are called
   (a) chromatin
   (b) centromeres
   (c) genes
   (d) sister chromatids (4.2) K/U
3. In male mammals, meiosis results in the formation of
   (a) one haploid gamete
   (b) one diploid gamete
   (c) four haploid gametes
   (d) two diploid gametes (4.3) K/U
4. Each parent passes on to its offspring only one of its two alleles for a gene. What is this phenomenon called?
   (a) dominance
   (b) codominance
   (c) the law of segregation
   (d) the law of independent assortment (5.1) K/U
5. Which of the following procedures is an example of assisted reproductive technology? (4.4, 6.2, 6.3) K/U
   (a) transposition
   (b) laser assisted hatching
   (c) DNA fingerprinting
   (d) all of the above
6. What is the probability of flipping a coin three times and getting heads all three times? (5.1) K/U
   (a) $\frac{1}{3}$
   (b) $\frac{2}{3}$
   (c) $\frac{1}{6}$
   (d) $\frac{1}{8}$
7. What is the name for the circular pieces of DNA that can be used to introduce new genes into an organism? (5.1) K/U
   (a) plasmids
   (b) viruses
   (c) bacteria
   (d) recombinant DNA
8. What pattern of dominance is shown in **Figure 1**? (5.2) K/U
   (a) complete dominance
   (b) incomplete dominance
   (c) codominance
   (d) none of the above

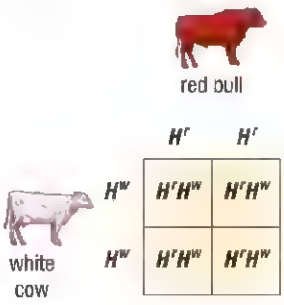

Figure 1

9. Which of the following options is a correct complementary base pair of DNA? (6.1) K/U
   (a) adenine and thymine
   (b) cytosine and thymine
   (c) guanine and adenine
   (d) guanine and thymine

Match each term on the left with the most appropriate description(s) on the right.

10. (a) dominant trait — (i) expressed as a blending of traits
    (b) recessive trait — (ii) expressed only if the genotype is homozygous for the trait
    (c) incompletely dominant trait — (iii) expressed along with another trait
    (d) codominant trait — (iv) always expressed when present in the genotype (5.2) K/U

11. (a) dominance — (i) A parent passes on only one of its two alleles for a trait.
    (b) law of segregation — (ii) Alleles of a heterozygous individual separate during gametogenesis.
    (c) law of independent assortment — (iii) Recessive alleles show in the phenotype only if they are the only alleles in the genotype. (5.1, 5.7) K/U

Write a short answer to each question.

12. In what molecules is genetic information stored? (4.1) K/U
13. At which phase of meiosis does crossing over occur? (4.3) K/U
14. Why is Down syndrome also called trisomy 21? (4.4) K/U
15. When a dominant allele and a recessive allele appear in the genotype of an insect with incomplete dominance for a given characteristic, which trait(s) appear(s) in the phenotype? (5.2) K/U
16. What is the likely coat colour of a dog that has codominant black and white alleles for coat colour? (5.2) K/U
17. In X-linked inheritance, which sex is more likely to possess the recessive phenotype? Which sex is more likely to be a carrier of the recessive allele? (5.3) K/U
18. Describe autosomal inheritance. (5.3) K/U
19. Which of Mendel's laws of inheritance is shown in **Figure 2**? (5.1, 5.7) K/U

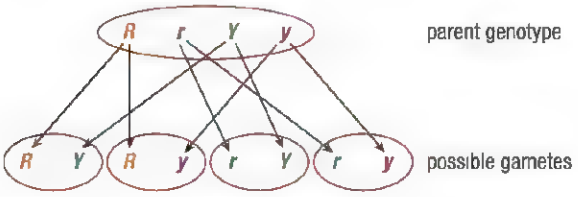

Figure 2

20. What is a dihybrid cross? (5.7) K/U
21. What are the three chemical components of a DNA nucleotide? Describe their arrangement within a double-stranded DNA molecule. (6.1) K/U
22. How did Rosalind Franklin's research help James Watson and Francis Crick form their model of the DNA molecule? (6.1) K/U
23. What is a point mutation? Use diagrams to illustrate and compare substitution, deletion, and insertion mutations. (6.2) K/U T/I C
24. Describe coding DNA. Describe non-coding DNA. (6.3) K/U
25. Briefly describe three applications of biotechnology. (4.2, 6.3, 6.4) K/U T/I

Understanding

Indicate whether each of the statements is true or false. If you think the statement is false, rewrite it to make it true.

26. DNA is located in genes that are located on chromosomes. (4.1) K/U
27. DNA banks can be used to evaluate chromosome numbers and diagnose genetic disorders. (4.4) K/U
28. There are few applications of reproductive technologies in agriculture and wildlife conservation. (4.4) K/U
29. The expression of human ABO blood types involves both dominant and codominant traits. (5.2) K/U
30. About 98 % of the DNA in the human genome codes for genes. (6.3) K/U
31. Recombinant DNA is a fragment of DNA made by combining nucleotide sequences that would not be found together naturally. (6.4) K/U

Write a short answer to each question.

32. In general, how does the genetic material of offspring produced by sexual reproduction compare to that of their parents? How does the genetic material of offspring produced by asexual reproduction compare to that of their parent? (4.1) K/U
33. Define and compare oogenesis and spermatogenesis. Explain how oogenesis and spermatogenesis are related to gametogenesis. (4.3) K/U
34. How does crossing over affect the genetic diversity already ensured by the process of independent assortment? (4.3) K/U T/I
35. Explain horizontal gene transfer. How does it work to the green sea slug's advantage? (4.5) K/U T/I
36. Write an analogy that compares traits and characteristics to genes and alleles. (5.1) K/U T/I
37. Give an example of a human blood type that exhibits a dominant trait and an example of a human blood type that exhibits a codominant trait. (5.2) K/U T/I

38. Consider inherited mutations such as sickle-cell anemia and lactose tolerance. How do they make a person better adapted to his or her environment in certain circumstances? How have these mutations persisted in the human population? (5.5) T/I
39. List two laws of heredity that Mendel discovered as a result of his experiments on pea plants. Briefly describe each law. (5.1, 5.7) K/U
40. Contrast continuous variation and discontinuous variation, and give an example of each. (5.7) K/U
41. How did James Watson and Francis Crick explain Erwin Chargaff's observation of the equal proportions of bases? (6.1) K/U
42. Give an example of a disease caused by a point mutation, and tell which type of point mutation causes it. (6.2, 6.5) K/U
43. Describe and illustrate the process of transposition of a gene from one chromosome to another within a genome. What is a transposon? (6.2) K/U T/I C
44. What is the technological breakthrough shown in **Figure 3**? What is its importance in genetic research? (6.2) K/U

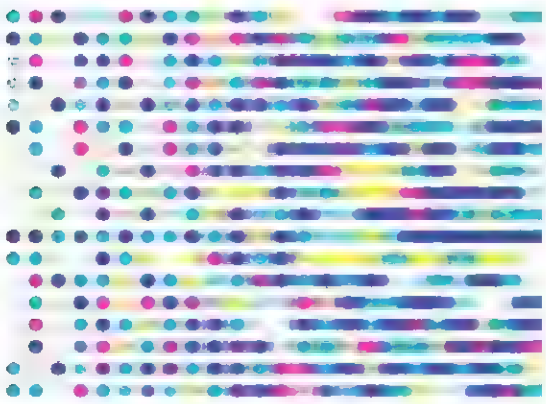

Figure 3

Analysis and Application

45. In meiosis, a cell produces four haploid daughter cells that carry different combinations of genes. (4.1, 4.2, 4.3) T/I
    (a) What is the advantage to a species of producing four haploid daughter cells carrying different combinations of genes instead of two diploid daughter cells that are genetically identical?
    (b) What is the disadvantage?
46. Why do the gene pairs noted by Mendel behave in a way similar to the way that chromosomes behave during the processes of gamete formation, fertilization, and reproduction? (4.1, 4.2, 4.3) T/I
47. Compare the chromosomes of a cell to pairs of socks in a closet. (4.1, 4.3) T/I A
    (a) Are the sock pairs more comparable to the chromosomes of a haploid cell or a diploid cell? Explain.
    (b) Suppose the sock pairs were to undergo meiosis. How would they look after crossing over?
    (c) How could the sock pairs be more comparable to a haploid cell?
    (d) Do you have socks that are comparable to a polyploid cell? Explain.
48. What are the principal differences between mitosis and meiosis? (4.2, 4.3) T/I
49. What are two differences between meiosis I and meiosis II? (4.3) T/I
50. One day at the nursery, you see an attractive new plant for your garden. You choose the lavender-flowered variety over the white-flowered variety. The nursery owner assures you that the plant is self-pollinating. After the plant flowers and goes to seed, you harvest the seeds and plant them. Of the 106 plants that grow from these seeds, 31 have white flowers. Using a Punnett square, determine whether your original plant was heterozygous or homozygous and whether lavender or white flowers are dominant. (4.1, 5.1) T/I C A
51. In a certain variety of plant, there are two alleles for seed colour—green (*G*) and yellow (*g*). The green allele is completely dominant over the yellow allele. Suppose that some of the offspring (F_1 generation) of a pair of green-seeded plants (P generation) have yellow seeds. (4.1, 5.1) T/I C A
    (a) What must be the genotypes of the P generation? Are those plants homozygous or heterozygous for seed colour?
    (b) What are the genotype(s) of the F_1 generation? What proportion of the plants in the F_1 generation is homozygous for seed colour and what proportion is heterozygous for seed colour?
    (c) What are the phenotypes of the F_1 generation?
    (d) Construct a Punnett square to show the genotypes of the offspring (F_2 generation) of two of the yellow-seeded F_1 generation.
    (e) What would the genotype(s) and phenotype(s) of the F_2 generation in part (d) be?
    (f) Is this problem an example of a monohybrid cross or a dihybrid cross? Explain.
    (g) Could you have performed a test cross to answer the questions about the F_1 generation? Explain.

52. Suppose you were to perform a test cross to determine the genotype of one of the parent plants (P generation) in Question 51. (5.1) T/I C A
    (a) What must be the genotype of the plant with which you cross it?
    (b) The genotypes of the offspring turn out to be about 25 % *GG*, about 50 % *Gg*, and about 25 % *gg*. About what percentage of offspring have green leaves and about what percentage have yellow seeds?
    (c) What is the genotype of the parent plant from Question 51?
53. How can there be only four different human blood types when there are six different human blood genotypes? (5.2) T/I A
54. Suppose a classmate of yours were to state that her father had male pattern baldness (**Figure 4**) because he inherited it from his father. (4.1, 4.3, 5.1, 5 3)

Figure 4

    (a) Is male pattern baldness inherited via sex chromosomes or autosomes?
    (b) Is it a sex-linked trait? If so, is it an X-linked trait or a Y-linked trait?
    (c) Based on your responses to the above questions, would you agree or disagree with your classmate?
55. The pedigree in **Figure 5** shows the instance of attached earlobes in three generations of a family. State, by sex and generation, which members of the family have attached earlobes. Make note of any individuals who are identical twins or fraternal twins. (5.3) T/I A

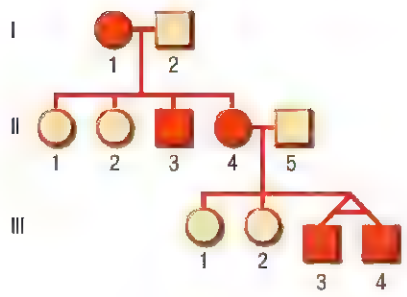

Figure 5

56. To better study Huntington's disease, scientists have genetically modified a mouse that has the human Huntington's disease gene. (5.4) T/I A
    (a) What do you call an organism that is genetically modified explicitly for the study of a human disease?
    (b) What are two valuable aspects of such genetically modified organisms in the study of human diseases?
57. In what class of gene are BRCA1 and BRCA2? How, specifically, do BRCA1 and BRCA2 affect a woman's chances of developing breast cancer? (5.5) T/I A
58. How many possible gametes can a parent who is heterozygous for each of two traits produce? Explain. (5.7) T/I A
59. Copy and complete the Punnett square (**Figure 6**) with the results of a dihybrid cross of two individuals with genotypes of *AaBb*. (5.7) T/I C A

	AB	***Ab***	***aB***	***ab***
AB				
Ab				
aB				
ab				

Figure 6

60. Colourblindness is a sex-linked trait. A woman whose father is colourblind has normal vision. She has a child with a man who has normal vision. What are the possible phenotypes for that child? (5.3) T/I

61. In cats, black fur colour has incomplete dominance over white fur colour. A curly coat is dominant to straight hair. Cross two cats that are heterozygous for both conditions. (5.2, 5.7) T/I
    (a) What are the possible phenotypes and genotypes of the offspring?
    (b) What are the possible phenotype and genotype ratios of the offspring?

62. How might a DNA microarray be used to differentiate cancer cells from normal cells? (6.2) T/I A

63. Compare and contrast point mutations and chromosomal mutations. (6.2) T/I A

64. Why do you think bacteria are able to make human proteins when a human gene is introduced into them via a plasmid? (6.4) T/I A

65. Leber's congenital amaurosis is a type of blindness that is inherited on an autosome. Suppose a sufferer were to undergo gene therapy that successfully corrected the blindness. How would that affect the likelihood that the children of the former sufferer would inherit the condition? (4.4, 6.5) T/I A

Evaluation

66. How does meiosis enable organisms to maintain their chromosome numbers from one generation to the next? (4.3) T/I A

67. Consider a litter of kittens. How can they look so different from one other and from their parents when they have all inherited their genetic material from the same two cats? Include the roles of crossing over and independent assortment in your answer. (4.3) T/I A

68. Evaluate different types of efforts to preserve endangered species. (4.4, 6.3) T/I A
    (a) Name three assisted reproductive technologies that are used to help preserve endangered species.
    (b) What is the most important disadvantage to using assisted reproductive technologies to preserve endangered species?
    (c) List two methods of preserving endangered species other than assisted reproductive technologies.

69. Test crosses were once the only way to determine the genotype of an organism that expressed a dominant trait. Test crosses are used much less frequently now than they once were. (5.1) T/I A
    (a) What is the major disadvantage of test crossing?
    (b) What are the typical reproductive characteristics of organisms used in test crosses?
    (c) The gestation period of a horse is about 340 days. Would you expect test crossing to be a practical way to determine the genotype of a horse?
    (d) How have advances in molecular biotechnology reduced the need for test crosses?

70. If the recipient of a blood transfusion has a blood type that is incompatible with that of the donor, the recipient can suffer a life-threatening immune response. Copy and complete **Table 1** to show which blood types can safely accept which blood types. (5.2) T/I

Table 1

Donor blood type	Recipient blood type			
	A	B	AB	O
A	safe			
B			safe	
AB	unsafe			
O				

71. Why is it unlikely that a gene found on the Y chromosome but not on the X chromosome would be required for survival? (5.3) A

72. The gene for sickle-cell anemia has an overall harmful effect in an individual with a homozygous genotype, but can have an overall helpful effect in an individual who has a heterozygous genotype. Explain how this is possible. (5.3, 5.5) T/I A

73. Can a couple in which both partners are heterozygous for cystic fibrosis conceive a child without the disease? What is the probability that they will do so? (5.5) T/I A

74. Erwin Chargaff found that the percentages of adenine and thymine, and guanine and cytosine, in the DNA of organisms are always very similar. **Table 2** shows some of Chargaff's data. (6.1) T/I A

Table 2

Organism	Percentage of each nitrogenous base			
	A	T	G	C
Streptococcus	29.8	31.6	20.5	18.0
yeast	31.3	32.9	18.7	17.1
herring	27.8	27.5	22.2	22.6
human	30.9	29.4	19.9	19.8

(a) For the organisms in the table, round off the average percentage of adenine and thymine to the nearest factor of 10. Do the same for the percentages of guanine and cytosine.

(b) If a species has 28 % adenine in its DNA, what is the approximate percentage of each of the other three bases in its DNA?

(c) What does the fact that the bases adenine and thymine, and guanine and cytosine, occur in such similar percentages suggest about their physical relationships within DNA?

75. You may not think that you eat many soybeans, but you do. Soy sauce is a common ingredient in Chinese cuisine. Tofu and edamame are prominent in many Asian cuisines and are staples of vegetarian diets (**Figure 7**). Food additives made from soybeans, such as lecithin, are very common ingredients in processed foods. Soybean oil is also used in thousands of processed foods and as cooking oil in restaurants and homes. (4.2, 6.4) T/I C A

Figure 7

(a) In 2009, 77 % of soybean crops worldwide were genetically modified (GM). Most GM soybean varieties are modified for herbicide resistance, or tolerance (HT). What is the major advantage of HT?

(b) Would you expect farmers with HT crops to use more or less herbicide?

(c) Would you expect that the economic benefits of growing GM soybeans outweigh the costs?

76. In everyday conversation, the word "mutation" often has a negative connotation. Describe one human mutation that is more helpful than harmful. (6.2) C A

77. One of your classmates is arguing that genetic engineering makes it possible for bioengineers to create an animal that has any combination of characteristics—a dog with gills, for example. Give three reasons for that not necessarily being the case. (6.4, 6.6) C A

78. A man who is AB for blood type is married to a woman who is type O. Their first child has blood type O. The husband sues for divorce on the grounds that his wife has been unfaithful. You are called as an expert witness to give genetic evidence. What would you say? (5.2) T/I A

Reflect on Your Learning

79. Suppose that you have just decided to have children, and you discover that some people in your family have suffered from cystic fibrosis. Would you want to undergo carrier testing? Would you seek out genetic counselling? Explain why or why not. T/I A

80. Suppose that you could send a letter back in time to Rosalind Franklin. Tell her about a field of bioengineering and the ways that it has improved people's lives. (Remember that her knowledge of genetics ended in the late 1950s, since she died in 1958.) T/I C

81. In Canada, there are no laws requiring that foods made from GM organisms be labelled as such. T/I C A

(a) Would you like to know which food products have GM ingredients? Explain why or why not.

(b) Recall that genetic engineers can combine genes from organisms that are very different from each other to create GM organisms—flounders and tomatoes, for example. Suppose you were a vegetarian. Would that change your opinion of whether or not foods with GM ingredients should be labelled? Explain why or why not.

82. Consider the many medical and legal ways that information from your DNA can be put to use. You were probably screened for genetic disorders before you were born and for more shortly afterwards. If you choose to have biological children, you may want to undergo genetic screening beforehand. If you commit a crime, a sample of your DNA will be banked, and it could be used to acquit or convict you of a later crime. A

(a) In which situations do you feel that such sacrifices of privacy are worth the benefits to yourself and to society?

(b) What if the Canadian government were to decide to bank samples of all citizens' DNA as they are born? Would that change your opinion?

83. Most cattle raised for beef are fed a diet based on corn. The digestive system of cattle is better able to deal with grass and other leafy plants, but corn is much cheaper. Feeding corn to cattle keeps the price of beef lower. Unfortunately, because of their digestive systems, cattle must be fed antibiotics along with corn so that they gain weight quickly enough to be profitable, and so they do not get sick or die. Beef

cattle also often live in very densely packed feedlots, which adds to the possibility of infection. In 2010, there were more than 5 million beef cattle in Canada. Most of those were fed corn and given antibiotics. T/I A

(a) Are you concerned that such widespread use of antibiotics could contribute to antibiotic resistance? Why or why not?

(b) If beef cattle are fed grass instead of corn, they often require fewer antibiotics to stay healthy. But it is also more expensive to feed them, and they may not grow as fast. As a result, cattle ranchers have to charge more for their product, and beef costs more for the consumer. Do you fear the potential for antibiotic resistance more than a shortage of affordable beef? Explain.

(c) Horizontal gene transfer between strains of bacteria known in beef cattle and harmful strains known in humans may be possible. Does that knowledge change your response to (b)? Explain why or why not.

84. Do you feel that genetic modification of organisms should be monitored by the Canadian government and/or an international organization such as the Food and Agriculture Organization? Why or why not? A

85. Suppose that you were part of a couple concerned about conceiving a child with Huntington's disease. T/I A

(a) How would you go about evaluating the probability of doing so?

(b) Once you had learned about the probability of conceiving a child with Huntington's disease, what help would you look for in making a decision?

86. Some companies sell genetic tests directly to consumers, who either test themselves at home or send in saliva to be tested in the company's lab. These tests tell you if you are at high risk for a disease with a genetic component, such as Alzheimer's disease or heart disease. T/I A

(a) Would you want to know your risk for Alzheimer's disease, knowing that there is at this point no cure?

(b) Would you want to know your risk for heart disease, knowing that even though there is no cure, lifestyle changes and medication may be effective?

(c) With whom, if anyone, would you share the knowledge that you were at high risk for either of the above diseases?

87. In 1999, an 18-year-old man named Jesse Gelsinger volunteered for an experimental gene therapy procedure that was meant to repair his liver, which had been damaged by a genetic disorder. Doctors introduced the new liver genes via a modified common cold virus. Sadly, Gelsinger suffered a catastrophic reaction to the treatment, and he died just a few days later. More than 10 years later, gene therapy is still not available, and experiments on humans have declined greatly because of the fear of serious side effects. Given these problems, but also given what you have learned about the promise of gene therapy in this chapter, do you feel that continuing to research it is worth the money and time? T/I A

88. Genetic engineers may eventually be able to change the inherited traits of human embryos. T/I A

(a) In what circumstances, if any, do you think you would allow your child's inherited traits to be changed in this way?

(b) Would you have wanted your parents to allow your own traits to be changed in this way? Explain why or why not.

89. Which type of genetic research described in this unit did you find most encouraging? Most alarming? Explain your responses T/I C

Research

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90. Parthenogenesis is a means of asexual reproduction in organisms that usually reproduce sexually. In parthenogenesis, the female organism, without fertilization by a male, produces normal offspring.

Research parthenogenesis in the whiptail lizard (*Cnemidophorus neomexicanus*) of the southwestern United States (**Figure 8**). T/I A

Figure 8

(a) What is the genetic relationship between the mother and the young produced by parthenogenesis?

(b) How does the degree of genetic variation in populations produced by parthenogenesis compare to that of those produced by sexual reproduction?

(c) How does the degree of genetic variation in populations produced by parthenogenesis compare to that of those produced by cloning?

(d) Given its lack of genetic diversity, how well do you expect this population of lizards would tolerate a prolonged and significant change to its environment?

(e) Given your answer to (b) and (d), and given the many generations for which this population has been reproducing asexually, what would you expect about the stability of the environment in which it lives?

91. Review government and public health websites to learn about genetic testing in Canada. T/I C A
    (a) Which genetic tests are suggested by health officials in Canada under which circumstances?
    (b) How is the privacy of those test results protected?
    (c) What are direct-to-consumer (DTC) test kits?
    (d) List one advantage and one possible disadvantage of DTC tests

92. Nearly all the bananas we find in supermarkets are not only the same variety, they are also clones. The ripening characteristics and durability of the Cavendish variety (**Figure 9**) are so convenient to banana growers and shippers that most large growers grow it exclusively. T/I C A
    (a) Research the means by which Cavendish banana growers produce new banana plants. Research potential threats to the Cavendish.
    (b) Write a paragraph describing how this means of reproduction could make our banana supply very vulnerable.

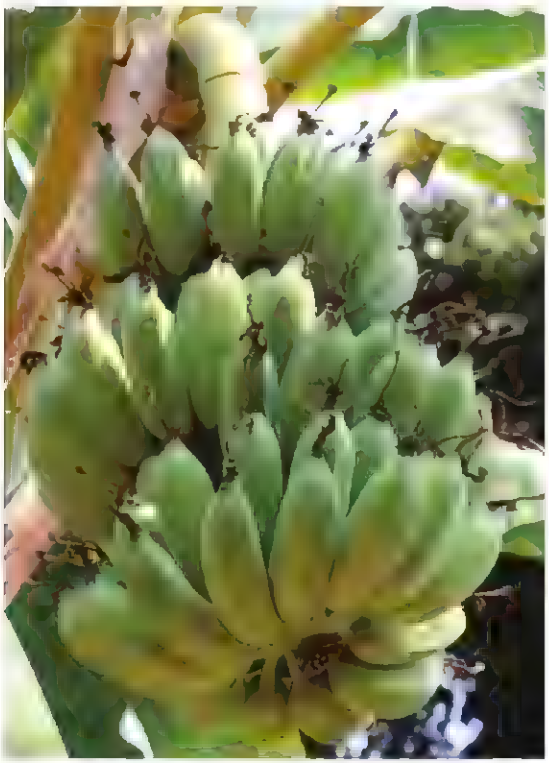


Figure 9

93. There has been a great deal of research into and experimentation with the genetic modification of goats. The goal of this work is to create goats that produce milk that could be processed into useful products such as spider silk and antibacterial substances. T/I A
    (a) Why do you think goats might be such useful subjects for genetic modification?
    (b) On the Internet, find one other product that goats have been genetically modified to produce.

94. Research the work of Reginald Punnett (1875–1967), the English geneticist who devised the Punnett square, and his collaborations with William Bateson (1861–1926). T/I C A
    (a) How well known was Gregor Mendel's work before 1900? How did Bateson help to popularize Mendel's work in England?
    (b) Briefly describe a major research project that Punnett and Bateson worked on together.
    (c) What were two important facts about Punnett's book *Mendelism*?
    (d) Aside from the Punnett square and *Mendelism*, what are three accomplishments of Reginald Punnett's that have contributed to our knowledge of genetics?

95. There are several methods of DNA fingerprinting. Research restriction fragment length polymorphism (RFLP), polymerase chain reaction (PCR), and short tandem repeat (STR) analysis. C A
    (a) Generally and briefly describe how DNA is traced in each method
    (b) Name two purposes for which each method is commonly used.

96. Biotechnology includes many varied and exciting fields of study. Which ones interest you the most? Research two jobs in the field and determine what level of education and/or what sort of training they require. T/I A

UNIT 3

Evolution

OVERALL EXPECTATIONS

- analyze the economic and environmental advantages and disadvantages of an artificial selection technology, and evaluate the impact of environmental changes on natural selection and endangered species
- investigate evolutionary processes, and analyze scientific evidence that supports the theory of evolution
- demonstrate an understanding of the theory of evolution, the evidence that supports it, and some of the mechanisms by which it occurs

BIG IDEAS

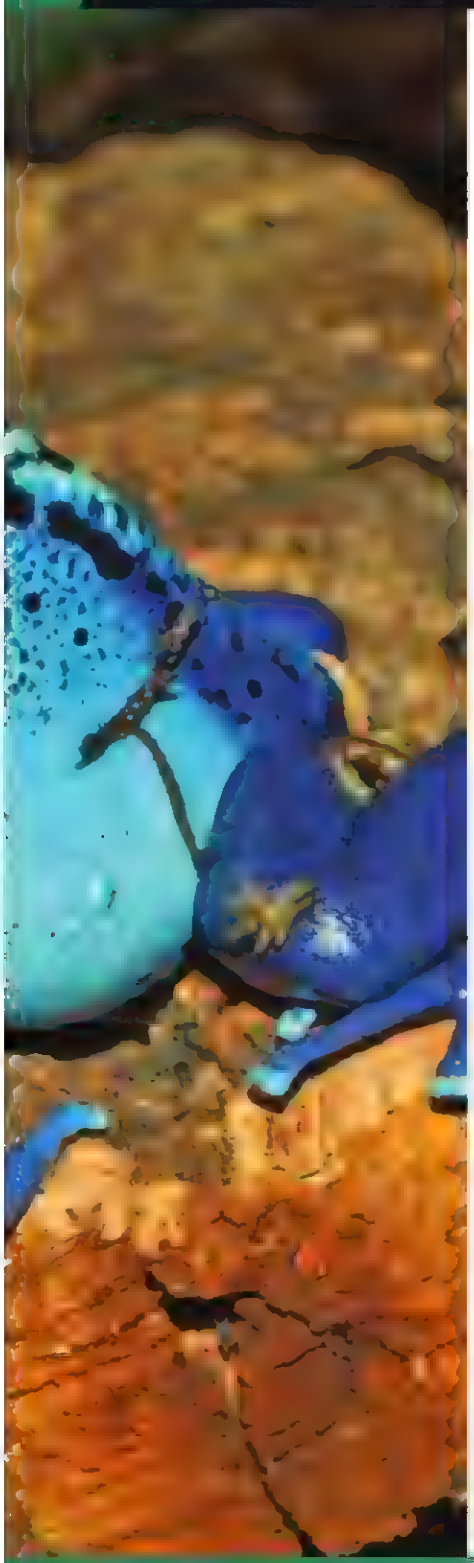
- Evolution is the process of biological change over time based on the relationships between species and their environments.
- The theory of evolution is a scientific explanation based on a large accumulation of evidence.
- Technology that enables humans to manipulate the development of species has economic and environmental implications.

UNIT TASK PREVIEW

In this Unit Task you will choose a current topic in applied evolutionary biology from medicine, conservation biology, agriculture, or from a field of your choosing. You will complete an analysis of the application, reviewing the evolutionary principles at work, what the theory predicts, and how the theory is applied to the situation in question.

The Unit Task is described in detail on page 378. As you work through this unit, look for the Unit Task Bookmarks to see how information in the section relates to the Unit Task.

FOCUS ON **STSE**



IN PURSUIT OF POISONS

Poisons can make powerful medicine. At first this might sound like a contradiction. How can a poison be of medical benefit? The answer lies in what ails you. We use a variety of drugs to kill infectious bacteria and parasitic organisms that have invaded our bodies. We also try to kill our own cells if they have become cancerous and are dividing out of control. Antibiotics, chemotherapy drugs, and other medicines are poisonous to their intended target. How do scientists go about finding these "poison pills"?

Many poisons are produced by living organisms. In their search for these poisons, evolutionary biologists often look for situations in which there is an ongoing evolutionary "arms race" between predator and prey or between pathogen and host. In these situations a species may have evolved chemical defences to deter a predator or to fight off infectious organisms.

The tropical rainforests of Central and South America are home to some dramatically coloured poison dart frogs. Their bright coloration serves as a warning to would-be predators that these frogs contain poisons. In addition to the poisons these particular frogs use to ward off predators, all frogs produce antimicrobial chemicals in their skin to resist infections. More than 100 of these chemicals have been isolated, and at least one is able to kill some strains of highly drug-resistant bacteria. Researchers believe these substances could become the basis for a powerful new generation of antibiotics. Ironically, the existence of many of these same frog species is threatened by a serious fungal skin disease. The fungus is being introduced to new ecosystems by human activity. Without previous exposure to the fungus, many frog species have not had an opportunity to evolve a chemical defence against it.

Scientists apply evolutionary or Darwinian thinking to all aspects of healthcare and indeed to all aspects of biology. As you will learn, the theory of evolution provides important insights and informs our understanding of individuals, species, communities, and entire ecosystems. Evolutionary biology is a vital tool for maintaining and enhancing our own health as well as that of the diversity of life on Earth.

Questions

1. Many potent medicines are derived from plant toxins, while relatively few come from animal sources.
   (a) Why might plants have evolved more poisons than animals?
   (b) Would you expect plant poisons to be more concentrated in leaves, fruits, or roots? Explain your reasoning.
   (c) Fruits and roots make up a larger portion of a typical human diet than leaves. Are you surprised? Explain.

2. Given that many drugs are actually biological poisons designed to kill certain types of cells, is it surprising that many drugs have adverse side effects? What does this suggest about the challenges of developing safe and effective drugs to combat disease?

3. When exposed to sunlight, human skin produces vitamin D, an extremely important compound. Biologists are concerned that lifestyle changes could cause widespread vitamin D deficiency. How does this concern reflect Darwinian thinking?

4. Some species of Amazonian snakes are able to eat poison dart frogs. How does this illustrate the concept of an evolutionary arms race?

UNIT 3 ARE YOU READY?

CONCEPTS

- recognize and use proper terminology related to genetics and reproduction
- explain the significance of mutation and genetic variation
- understand scientific approaches to gathering evidence and testing hypotheses
- understand ecological relationships and adaptations

SKILLS

- interpret phylogenetic trees
- calculate simple ratios and probabilities
- evaluate information sources

Concepts Review

1. Describe the structure and function of each of the following: K/U
   (a) chromosome
   (b) DNA
   (c) gene
   (d) allele
2. (a) Explain the meaning and relationship between the terms "haploid," "diploid," and "polyploid."
   (b) Under what circumstances do diploid and polyploid organisms produce haploid cells? K/U
3. Explain how each of the following processes contributes to genetic diversity: K/U
   (a) independent assortment of homologous chromosomes
   (b) crossing over
   (c) mutation
4. Assume that a portion of a DNA molecule has the following base sequence: A A T C G T T C A C G G. Rewrite this sequence to illustrate an example of
   (a) a base substitution
   (b) a deletion
   (c) an insertion K/U
5. What causes mutations to occur? K/U
6. Why are mutations described as being neutral, beneficial, or harmful? Provide examples to support your answer. K/U
7. It is sometimes possible for a mutation to be beneficial in one situation and not in another. What role does the environment play in creating these different situations? K/U T/I
8. Many species are involved in symbiotic relationships with other species. Define and give an example of each of the following forms of symbiosis: K/U
   (a) mutualism
   (b) commensalism
   (c) parasitism
9. **Figure 1** shows a Venn diagram. Copy Figure 1 into your notebook and complete it to compare asexual and sexual reproduction. Include references to genetic diversity, advantages, disadvantages, and the cellular processes involved. K/U T/I

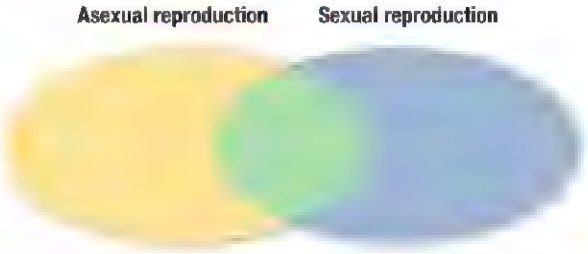


Figure 1

10. What are the advantages to a population or species that has a high degree of genetic variation? K/U
11. Many species occupy similar ecological niches in different parts of the world. Brainstorm examples of the following: T/I
    (a) a top carnivore in Africa and a top carnivore in North America
    (b) a large grass-eating herbivore in the Canadian prairies and a large grass-eating herbivore in an African savannah
12. (a) What are invasive species?
    (b) Why are invasive species able to outcompete species that are native to a particular area? K/U T/I
13. Over the past 60 years, many species of bacteria have become resistant to one or more types of antibiotics. T/I
    (a) Make a series of labelled diagrams to describe and explain how antibiotic resistance develops over time.
    (b) Would a mutation that increases antibiotic resistance in a species of bacteria be considered harmful or beneficial? Explain.

14. Examine the photograph of the poinsettia plant in **Figure 2.** T/I A
    (a) Would you expect this plant to be wind or animal pollinated? Explain your reasoning.
    (b) What are often thought of as red poinsettia "flowers" are actually brightly coloured red *leaves*. Most plants produce only green leaves. What type of genetic event might have produced this trait in the poinsettia?
    (c) What other plants have leaves that perform a non-photosynthetic function? How is this trait advantageous to those particular plants?

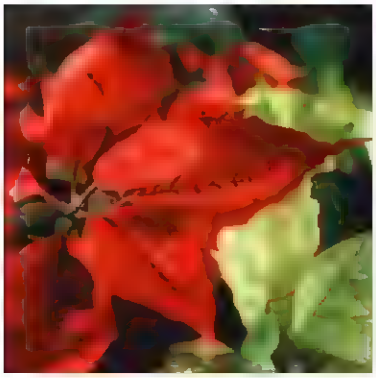


Figure 2

15. Explain the advantages of each of the following adaptations to life on land: T/I
    (a) Gymnosperms produce pollen and seeds.
    (b) Mammals and birds are warm blooded.
16. What is the difference between a scientific hypothesis and a scientific theory? Under what circumstances can a hypothesis eventually become a theory? T/I
17. Scientists rely heavily on carefully controlled observations of the natural world and experiments for gathering data. Galileo, for example, believed that the only way to determine if a heavy ball falls faster than a lighter ball was to drop them and measure their speed. Do you agree with Galileo? Is there a better or more reliable way to find out which ball falls faster? T/I

Skills Review

18. Make the following conversions based on the scales provided: K/U
    (a) scale: 1 m = 200 years
    conversion: _____ m = 8000 years
    (b) scale: 1 m = 50 MY (million years)
    conversion: 35.5 m = _____ years
19. Insert the correct value to produce a matching ratio: K/U
    (a) The ratio 6:4 is equivalent to _____:20.
    (b) The ratio 11:3 is equivalent to 44:_____.
20. Examine the phylogenetic tree in **Figure 3** and answer the following: K/U
    (a) Which species is most closely related to wheat? Explain.
    (b) Which are more closely related: ferns and moss, or ferns and orchids? Explain.
    (c) Kelp are not plants. According to this diagram, do kelp share a common ancestor with each of these plant species? Explain.
    (d) According to this diagram, what shared common ancestor places ferns in a clade with spruce?
    (e) What shared common ancestor excludes ferns from the *largest clade that does not* include the fern?

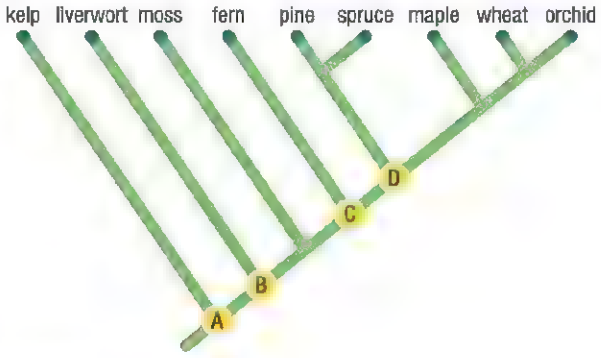


Figure 3

21. A population contains two types of individuals: type A and type B. The population consists of 40 individuals. Determine how many are A and how many are B, if they occur in the following ratios. Round off to the nearest whole number. K/U
    (a) 4A:1B
    (b) 2A:3B
    (c) 11A:5B
22. (a) What is a science journal?
    (b) What are the advantages of peer review?
    (c) What is an abstract? K/U T/I
23. Students often use the Internet as a tool for conducting online research. When you use the Internet, what criteria can you use to determine whether or not the information on a website is credible? T/I

CAREER PATHWAYS PREVIEW

Throughout this unit you will see Career Links in the margins. These links mention careers that are relevant to evolution. On the Chapter Summary page at the end of each chapter you will find a Career Pathways feature that shows you the educational requirements of the careers. There are also some career-related questions for you to research.

CHAPTER 7

The Theory of Evolution

KEY CONCEPTS

After completing this chapter you will be able to

- explain how living things are able to change over time
- assess the many types of evidence that support the theory of evolution
- describe the contributions of Charles Darwin and other scientists
- explain and model the process of natural selection
- provide examples of how modern advances in science have enriched and supported our understanding of evolution
- outline the timing of major events in the history of life on Earth

What Is a Scientific Theory?

The word "theory" has two common meanings—an everyday meaning and a scientific one. In everyday language, "theory" is often used to mean "an educated guess" or one of many possible explanations about some phenomenon. When someone says "I have a theory . . . ," they usually mean that they are unsure but think they might know how to account for some observation.

In science, such tentative explanations are called hypotheses. A scientific theory is much more than an educated guess. A scientific theory is an explanatory model that accounts for a very large body of evidence. Scientific theories provide a basis for explaining observations of the natural world and for making testable predictions.

You are already familiar with two powerful scientific theories: cell theory and atomic theory, and you have no doubt heard of the theory of gravity. These theories attempt to explain our observations of the universe around us: the organization of living things, the organization of matter, and the main force that both holds you down on Earth's surface and governs the motions of bodies in our solar system and beyond. Unlike tentative guesses, a scientific theory is founded on a large body of evidence that gives scientists great confidence in the theory. That does not mean that these theories are complete or perfectly accurate. All scientific theories are considered tentative and open for revision and refinement as new evidence is gathered. However, scientists would be shocked to find an animal without DNA, an atom without electrons, or an apple that "fell up."

Once established, scientific theories are of great practical value. They allow us to make accurate and precise predictions, enabling us to perform tasks as complex as DNA fingerprinting and landing spacecraft on the surface of Mars.

As you will learn in this chapter, the theory of evolution is a scientific theory based on a large body of evidence that can be used to explain the history of life on Earth. It allows scientists to make accurate and useful predictions. The evidence includes fossils of ancient life forms, genetic analysis, comparative anatomy, and the distribution of living things on Earth.

STARTING POINTS

Answer the following questions using your current knowledge. You will have a chance to revisit these questions later, applying concepts and skills from the chapter.

1. The cell theory and the atomic theory were not always widely accepted. Do you accept these scientific theories as valid? If so, why? If not, why not?
2. Scientists gain confidence in their theories when they have more than one kind of supporting evidence. Why do you think this is so? Can you think of other situations in which more than one type of evidence is used to support a theory or prediction?
3. Evolutionary biologists, and most children, are fascinated by dinosaurs. In what way do you think fossils of dinosaurs might provide evidence of evolution?
4. Mutations can result in heritable changes in the phenotype of an individual. What do you think the long-term effects would be if many mutations accumulated over time?

Mini Investigation

Puzzling over Evidence

Skills: Predicting, Performing, Observing, Analyzing

SKILLS HANDBOOK A2.1

Scientists gain an understanding of nature and natural processes by carefully gathering and analyzing evidence. As evidence accumulates, scientists look for patterns and begin to formulate ideas about underlying relationships. As patterns emerge, scientists may begin to generate and test hypotheses and make predictions. In this activity you will model this process by arranging evidence, drawing inferences, and making predictions in order to solve the puzzle. Think of each piece of the puzzle as representing a piece of scientific evidence.

Equipment and Materials: large envelope holding 14 jigsaw pieces; three blank jigsaw pieces

1. Remove eight puzzle pieces at random from your envelope. (Unused evidence must remain in the envelope.)
2. Attempt to arrange the puzzle pieces. Examine and describe your "puzzle evidence." Record your initial thoughts on what the puzzle picture might be. Make a prediction about the complete puzzle image. What do you think it illustrates?
3. Remove two more puzzle pieces from the envelope. Incorporate them into your puzzle arrangement. If possible, make a prediction about the overall puzzle image. What do you think this completed puzzle will show?
4. Look at the gaps in your puzzle. These gaps represent missing evidence. Make a prediction about one of the missing puzzle pieces. Use a blank jigsaw piece to draw a picture of your predicted puzzle piece, and put it in place.
5. Repeat Steps 3 and 4 two more times. Each time, revise and refine your prediction about the overall puzzle picture. Describe any matches between the new puzzle pieces and drawings you inserted into puzzle gaps.

A. Were all puzzle pieces equally useful, or were some pieces of evidence more valuable than others? Explain. T/I

B. How accurate were your drawings (predictions) of the gaps in evidence? T/I

C. How accurate was your first prediction? At what point did you become very confident in your prediction of the overall image? T/I A

D. Scientists gain confidence in theories as they accumulate evidence and test hypotheses. Even without all the evidence, scientists are often extremely confident in the overall validity of their theories. How does this activity model the relationship between evidence and theories? T/I A

7.1 Biological Change over Time

Figure 1 Snowshoe hares have evolved a number of adaptations that allow them to survive in winter.

Everywhere we look we see change. We live on a dynamic Earth that we share with millions of other species, comprising trillions of individual organisms. We observe life changing over time—individuals grow and mature and new generations come and go. The physical Earth also changes. Some changes are rapid, while others are slow and may go unnoticed. For example, you can observe a forest fire or the birth of a baby, but the changes that occur during ecological succession after a fire, and the changes that occur as a baby grows, are too slow to be seen on a day-by-day basis. The slower and more gradual the change, the more difficult it is to observe and investigate.

As you learned in the Diversity of Living Things unit, biologists are convinced that entire species change over time—they evolve. For example, over time snowshoe hares have evolved a number of adaptations that improve their survival in cold snowy winters. Their coat changes from brown to white for the winter and they have unusually wide feet for moving on deep soft snow (**Figure 1**). How do biologists detect such evolutionary changes in species, and what causes them to occur? How might the environment influence evolutionary changes in species?

Mutations: The Source of Genetic Variation

All species, including humans, exhibit genetic variation. The original sources of genetic variation are mutations, which are changes in genetic information. Mutations create new genes that provide a continual supply of new genetic information. Mutations that enter populations have an immediate and direct effect on individuals and also have the potential to influence future generations when those mutations are inherited.

neutral mutation a mutation that does not result in any selective advantage or disadvantage

harmful mutation any mutation that reduces the reproductive success of an individual and is therefore selected against; harmful mutations do not accumulate over time

beneficial mutation any mutation that increases the reproductive success of an organism; beneficial mutations are favoured by natural selection and accumulate over time

Mutations may be neutral, harmful, or beneficial. Most mutations are neutral and result in changes in DNA that have no immediate effect. **Neutral mutations** are those that provide no benefit or harm to the individual. **Harmful mutations** reduce the reproductive success of an organism. Examples of harmful mutations include those that lead to serious genetic disorders such as cystic fibrosis or Huntington's disease. **Beneficial mutations** produce a change in an individual's phenotype that gives the individual an advantage. Beneficial mutations give individuals a better chance of survival in their environment. For example, the sickle-cell allele gives carriers a high degree of resistance to malaria and dramatically enhances their chances of survival in regions where malaria is endemic.

The changes that arise in species through mutation can have significant consequences. Bacteria that have developed resistance to antibiotics are becoming more widespread as less-resistant strains are killed off (**Figure 2(a)**). Similarly, insect and other pest species that have developed resistance to various pesticides are becoming more common and difficult to control (**Figure 2(b)**). From the perspective of harmful bacteria or other pest species, any mutations that confer increased resistance are beneficial. Humans, however, would consider these mutations undesirable.

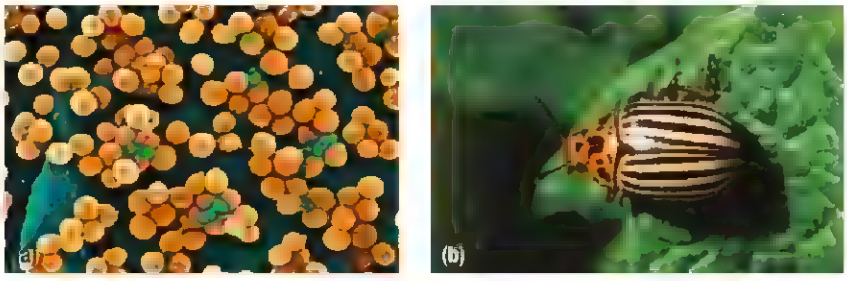


Figure 2 There is growing concern over the ability of disease-causing bacteria, such as (a) methicillin-resistant *Staphylococcus aureus* (MSRA), and insect pests, such as (b) the Colorado potato beetle, to evolve resistance to the antibiotics and insecticides we use to control them.

Some mutations have serious consequences for human health. For example, viruses, like living cells, carry genetic information that can undergo mutation. This means that populations of disease-causing viruses, such as the human influenza virus, are genetically variable and change over time. In rare instances, a mutation may increase the virulence of a virus or enhance its ability to spread. The result can be a deadly epidemic. Each year the World Health Organization and other health agencies try to predict which virus strains pose the greatest threat to humans and then work to develop an effective flu vaccine (**Figure 3**).

The most obvious changes to species are those that have occurred in domesticated species of plants and animals. In most cases, unmodified members of the original species still remain in the wild, but in other cases, such as that of certain breeds of domesticated cattle, the original species is now extinct. Changes that have occurred during domestication are a direct result of human manipulation.

Figure 3 Each year millions of Ontar ans receive the seasonal flu shot. A new vaccine is needed each year because the influenza virus is continuously chang ng.

Selective Breeding: Artificial Selection of Traits

The domestication of animals and plants is one of the most important technological innovations in human history. Domesticated plants and animals provide humans with the vast majority of our food supply and formed the basis for the development of modern civilizations.

Domestication is the changing of members of a species to suit human needs through controlled captive breeding. The controlled captive breeding process is referred to as **artificial selection**—*artificial* because it occurs in captivity rather than in a natural setting and *selection* because humans choose which specific animals or plants are bred. The breeder selects individuals that exhibit a desired trait or traits and uses these individuals as the parents of the next generation.

artificial selection directed breeding in which individua s that exhibit a particular trait are chosen as parents of the next generation; artificial selection is used to produce new breeds or varieties of plants and animals

Humans have been domesticating animals and plants for more than 10 000 years. You might be surprised to learn that the earliest animal to be domesticated was *Canis lupus*, the wolf (**Figure 4**). Of course we no longer refer to the domesticated variety as wolves, but rather as dogs. Genetic information provides compelling evidence that all modern breeds of dogs are descended from wolves (**Figure 5**). For this reason, dogs are considered a subspecies of wolves and have been given the scientific name *Canis lupus familiaris*.

Figure 4 The wolf, *Canis lupus*, is the ancestral species of all modern dog breeds.

Figure 5 Thousands of years of artificial selection have produced a great variety of dog breeds. During this time a single mutation is thought to have produced a dog with achondroplasia—a form of dwarfism. The descendents of this dog have since given rise to bassets and dachshunds.

Plants are equally capable of being selectively bred to suit our needs. For example, several thousand years of domestication of the wild sea cabbage, *Brassica oleracea*, have produced a wide array of vegetables (**Figure 6**). These diverse vegetables are, in fact, altered forms of the same original species. Differences in taste and appearance are the result of artificial selection acting over thousands of generations.

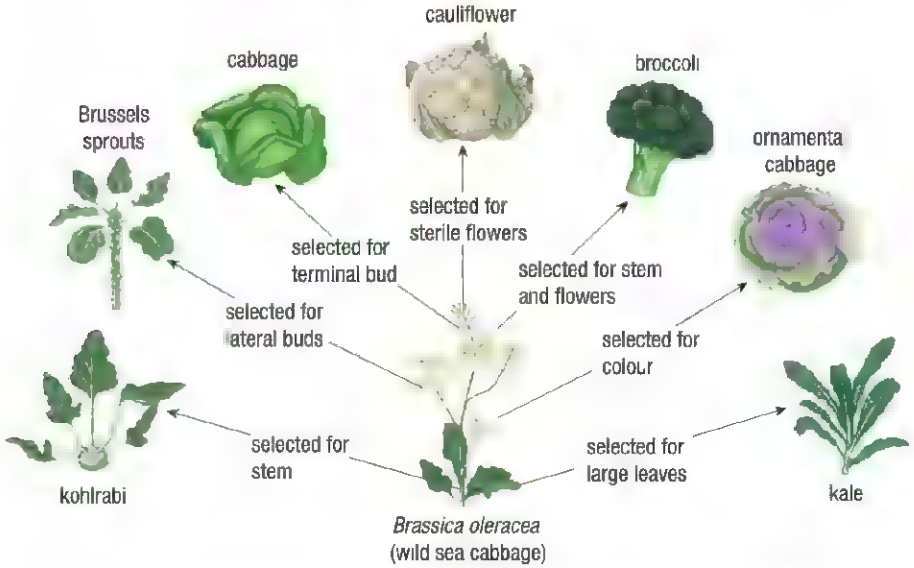


Figure 6 These seven well-known plants are domesticated varieties of the wild sea cabbage.

How does artificial selection work? How can animal and plant breeders turn wolves into Chihuahuas and St. Bernards, and wild cabbage into broccoli and kohlrabi? The process is surprisingly simple but, with the exception of modern genetic engineering techniques, very slow. The breeder usually has a particular feature in mind. For example, the Aboriginal peoples of Mesoamerica domesticated the tomato. Wild tomato plants produce nutritious but small fruit (**Figure 7**). As with any species, these plants exhibited variability—some were a little larger than others, some produced larger fruits, and some tasted better than others. Generation after generation, farmers selected seeds from the best plants to sow the next season. The seeds germinated, grew, flowered, and then cross-pollinated one another, producing more fruit with the desired traits. The farmers consumed most of the fruit as food but carefully examined the plants and saved seeds from the very best plants for sowing. These practices happened in many parts of the world (**Table 1**).

Table 1 Domesticated Species and Their Areas of Origin

Region	Domesticated species
Eurasia	apple, grape, dog, goat, horse
North and South America	peanut, potato, sunflower, llama
Africa	sorghum, Guineafowl

Figure 7 Beginning with (a) a wild species of tomato, farmers chose only those plants that exhibited the most desirable traits as a source of seeds for the next generation of planting. The result of thousands of generations is (b) the modern tomato.

The Science of Breeding

Most traditional animal and plant breeders would not consider themselves scientists, but what they do is often equivalent to a tightly controlled experiment. Each time breeders attempt to develop a new breed, they are testing a hypothesis and following a common set of procedures:

Hypothesis: Breeding selected individuals with certain favoured traits will result in the favoured traits becoming more prevalent and more pronounced.

Independent variable: breeding population (selected by the breeder)

Dependent variable: appearance of favoured trait in the population

Procedure:

1. Choose a useful species that can be bred in captivity.
2. Breed a large number of individuals.
3. Choose a trait that you wish to favour, such as large size, a particular colour, or sweetness.
4. Identify individuals that exhibit the favoured trait most strongly.
5. Breed only these individuals to produce the next generation of individuals.
6. Repeat Steps 4 and 5 over many generations.

In most cases the hypothesis is confirmed. The favoured trait becomes widespread throughout the population and also becomes enhanced. What early breeders likely did not expect was the degree to which the populations would change.

Modern breeding, particularly of crop plants, has undergone a revolution. Today scientists routinely use genetic engineering techniques to transfer what they hope will be beneficial genes from an individual of one species to an individual of another species. When successful, the genetically modified individual is often mass-produced by cloning. This practice can result in the widespread use of genetically modified plants with little or no genetic diversity. Although the pros and cons of genetic engineering are hotly debated, one thing is certain: these genes have all arisen in natural populations, and a loss in biodiversity also results in a loss of potentially valuable genes.

The Power of Artificial Selection

The most unexpected result of artificial selection is the production of individuals that exhibit traits that are far beyond the natural variability witnessed in the original breeding population. Adult Chihuahuas are not simply small wolves; they are much smaller than even the smallest of adult wild wolves, and they look very different. Giant red tomatoes can be a hundred times as large as the largest wild tomato fruit. Looking back to the traits of the first wild plants and animals used for breeding, no one could have imagined the power of selective breeding (**Figure 8**).

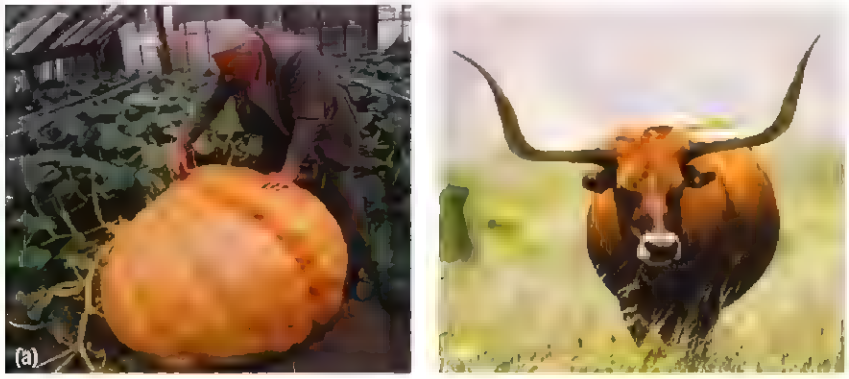


Figure 8 Artificial selection can produce surprising results, such as (a) this giant pumpkin or (b) the long horns of this Texas Longhorn.

Artificial selection methods can also reduce genetic diversity within a population. If breeders favour only certain traits within a population, then the many alleles linked to other versions of a particular characteristic are reduced or eliminated. Such a loss in diversity makes a population more vulnerable to disease. For example, large cobs of sweet corn might be favoured by plant breeders but might also be favoured by insect pests. In addition, some favoured traits can be linked to alleles that are detrimental. For example, some breeds of dogs are more prone to genetic disorders such as hip dysplasia and cancer because the alleles associated with these disorders are inherited along with the alleles that produce the favoured traits of those particular breeds.

THE 100 YEAR EXPERIMENT

The longest-running formal experiment in artificial selection is being conducted by the Illinois Agricultural Experiment Station. The experiment began in 1896 and is still under way. The purpose of the experiment was to test the effect of artificial selection on the oil content of corn seeds. The design involved two separate breeding experiments. In the first, corn plants were selected for high oil content, whereas in the second they were selected for low oil content. Over 76 years, the oil content increased from 5 % to more than 18 % in the first experiment, while it dropped to less than 1 % in the second (**Figure 9**). This evidence proves that the process of artificial selection can indeed be used to dramatically increase or decrease oil content in corn seeds.

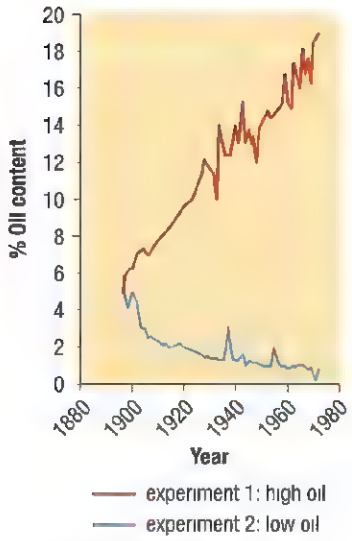


Figure 9 Artificial selection can increase or decrease the oil content in corn.

LIMITATIONS OF ARTIFICIAL SELECTION: THE INFLUENCE OF MUTATIONS

Not all attempts at artificial selection have been successful. Breeders cannot create traits that do not already exist in some form within the population. If there are no genes for blue roses (long sought after by flower lovers), then no amount of crossbreeding will create one. Breeders must work with the genetic diversity that already exists in the population or resort to genetic engineering technology to alter it. This does not mean that new mutations cannot arise, however, and when this happens the breeder has new material with which to work. There is always room for hope that someday a mutation will occur that gives rise to a truly blue rose.

Beneficial or neutral mutations have a good chance of being passed on to future generations because they are either favoured or go unnoticed. In contrast, mutations that cause harm, or produce an undesirable trait in an individual, have little influence on the potential success of artificial selection efforts. Breeders simply do not choose such individuals for breeding, and therefore the harmful mutations are not passed on to the next generation. In rare circumstances, however, an undesirable trait may accompany a beneficial one. An interesting example has occurred in the breeding of strawberries. Ontario breeders routinely attempt to develop plants that are more tolerant of cold. This would allow the plants to be grown farther north. Unfortunately, while the breeding programs have produced a number of strawberry plants that are quite hardy, these plants produced berries that are white on the inside. The breeding of these plant varieties was discontinued based on the expectation that consumers would not be willing to buy these odd-coloured berries.

CAREER **LINK**

Animal or Plant Breeder

Animal or plant breeders select individuals with desirable traits and breed them. To learn more about becoming an animal or plant breeder,

GO TO NELSON SCIENCE

UNIT TASK **BOOKMARK**

Consider how you can apply an understanding of genetic changes and selection as you work on your Unit Task.

Implications for Natural Populations

How can we apply our current understanding about genetics and artificial selection to the millions of species that exist in the wild? We should first recap what we already know about genetics:

- All species exhibit genetic variation.
- Mutations produce heritable changes in individuals, and these changes may be beneficial, harmful, or neutral.
- Some species, such as bacteria and insects, can change over relatively short periods of time.
- Some domesticated species have changed dramatically under the influence of artificial selection.

These observations are based on a large number of species that have been domesticated over relatively short periods of time—at most over several thousand years. How, then, might similar processes influence the populations of all species on Earth? If we can begin with a population of wolves and change them into hundreds of distinct breeds of dog, what might happen to a species over thousands or millions of years living under natural conditions?

One of the challenges faced by biologists trying to answer these questions is how and where to obtain useful evidence. You can imagine that one of the most useful places for biologists to look would be back in time. Biologists do not have time machines, but fortunately Earth keeps some records of the history of life (**Figure 10**).

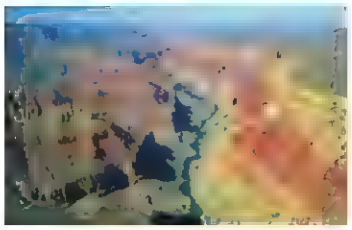


Figure 10 The Grand Canyon was formed by erosion. The Colorado River has cut through and exposed sedimentary deposits that are hundreds of millions of years old.

7.1 Summary

- Mutations create new genetic information and add genetic diversity to species.
- Beneficial mutations can have significant positive consequences for species.
- Artificial selection is a process in which individuals with particular favoured traits in each generation are chosen as the breeding stock for the next generation.
- When practised over many generations, artificial selection can produce dramatic changes in the traits of a population.
- Artificial selection is limited by the genetic variability within the breeding population.
- Artificial selection methods can reduce the overall genetic diversity of the population and therefore contribute to the loss of biodiversity.

7.1 Questions

1. The chances of any one individual being born with a beneficial mutation is very low. How then is it possible for mutations to play such a key role in evolution? K/U
2. How might it be possible for a neutral mutation to play an important role in the evolution of a species? K/U
3. Explain why harmful mutations do not accumulate over time and cause harm to populations. K/U
4. Use the evolution of antibiotic resistance to show how a mutation that is advantageous for one species can be harmful for another. K/U
5. Most wolves look quite similar. Use the domestication of dogs to illustrate the genetic diversity that is contained within the wolf population. K/U
6. All domestications of plants and animals begin with humans selecting a wild species living nearby. Use the Internet and other sources to research where each of the following domesticated species originated: K/U A
   (a) chicken
   (b) pig
   (c) cattle
   (d) corn
   (e) wheat
   (f) rice
   (g) chocolate
   (h) coffee
   (i) squash
7. Using a specific example, outline a hypothesis and simple step-by-step procedure a breeder could use to create a breed with a desired trait. K/U A
8. How have modern genetic engineering methods changed the way that plant breeders develop plants with new and potentially valuable traits? K/U
9. How do the genetic diversity of a population and mutation rates limit the ability of breeders to create organisms with desired traits? K/U A
10. In 1975, Japanese scientists discovered bacteria feeding on nylon in a chemical waste water pond. Nylon is a synthetic compound that was invented in 1935. Do online research to find out how mutations are thought to have produced this "nylon bug." Also learn how scientists have induced other bacteria to evolve the ability to feed on nylon. K/U
11. The discovery of the mutation responsible for the short legs of certain dog breeds was made by scientists at the National Human Genome Research Institute. Use the Internet and other sources to find out the following: K/U
    (a) Why were human geneticists interested in this dog trait?
    (b) How did the scientists conduct their study? How many dogs did they investigate?
    (c) What type of genetic change was responsible for this form of dwarfism?

GO TO NELSON SCIENCE

7.2 The Evolution of an Idea

immutable unable to change

Dating back at least as far as Aristotle (384–322 BCE), most Europeans accepted the idea that Earth and all living things had been created in their present forms and were **immutable**—they could not change and had not changed. The explanations for all natural phenomena were largely based on strongly held religious beliefs, philosophical debate, and thoughtful conjecture. It was not until science began to come of age in the fifteenth to eighteenth centuries that European philosophers recognized the importance of careful observation, experimentation, and deductive reasoning. During this time Copernicus, Galileo, and Newton demonstrated the power of science to explain the laws of motion, both on Earth and in the skies above.

The Seeds of an Idea

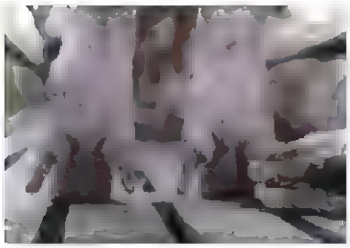


Figure 1 Many mammals, including pigs, have toes that do not reach the ground. Buffon puzzled over such useless features and considered them strong evidence that these species had changed over time.

A French scientist, Comte (Count) Georges Louis Leclerc de Buffon (1707–1788), applied scientific methods to the detailed study of anatomy. He closely examined animal body structures, considered their functions, and tried to account for his findings. Buffon was puzzled by anatomical features that seemed to serve no purpose. For example, he wondered why pigs have extra toes that do not reach the ground (**Figure 1**). Buffon believed the species had been created in a more perfect form but had changed over time.

At about the same time, other prominent scientists, including Carl Linnaeus (1707–1778) and Erasmus Darwin (1731–1802), also proposed that life changed over time. Erasmus Darwin, the grandfather of Charles Darwin, even suggested that all life might have evolved from a single original source.

While the seeds of evolutionary thought had been sown, these scientists could offer no explanation for how living things change. Without a plausible mechanism to explain how a species could change, their ideas remained speculative.

Adaptation and Heredity

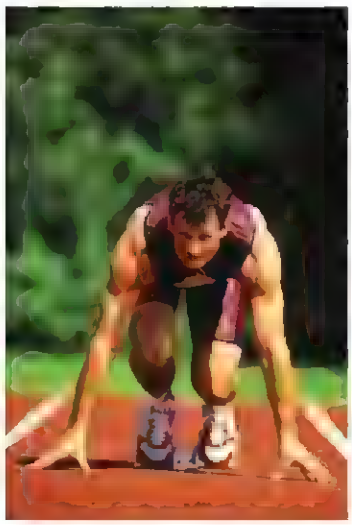


Figure 2 Muscles increase in size in response to vigorous exercise. Such an increase in size is considered an acquired characteristic.

A student of Buffon's, Jean-Baptiste Pierre Antoine de Monet, Chevalier de Lamarck (1744–1829), was the first scientist to offer a possible mechanism for the evolution of species. Lamarck proposed that evolutionary change resulted from two distinct principles.

Lamarck's first principle was that of *use and disuse*. He believed that structures an individual used became larger and stronger, while structures that were not used became smaller and weaker. On the surface, this principle seems to be supported by evidence from everyday observations. When athletes train, their muscles respond by getting stronger and increasing in size (**Figure 2**). Conversely, astronauts who return from space have reduced muscle mass resulting from lack of use. It seems reasonable to think that similar responses to use and disuse might occur among all organisms.

Lamarck's second principle was *the inheritance of acquired characteristics*. Lamarck believed that individuals could pass on to their offspring characteristics they had acquired during their lives. He believed, for example, that if an adult giraffe stretched its neck during its lifetime, then its offspring would be born with slightly longer necks.

To Lamarck, these two principles could explain why species were so adapted to their environment and how they could evolve if the environment changed. If the climate gradually cooled, animals might respond by growing a thicker coat of hair and would pass on this acquired characteristic to their offspring. Their offspring would then be born better adapted to the changing environment. The example of the giraffe's neck is often used to illustrate Lamarck's theory (**Figure 3**, next page).

Today we know that Lamarck's theory is flawed. Although organisms can acquire many characteristics during their lives, many features do not change in response to use, and features that do change are not normally heritable. For example, your vision does not improve the more you use your eyes. It is possible to stretch your neck slightly, but this will not alter your DNA, and your children will not be born with longer necks.

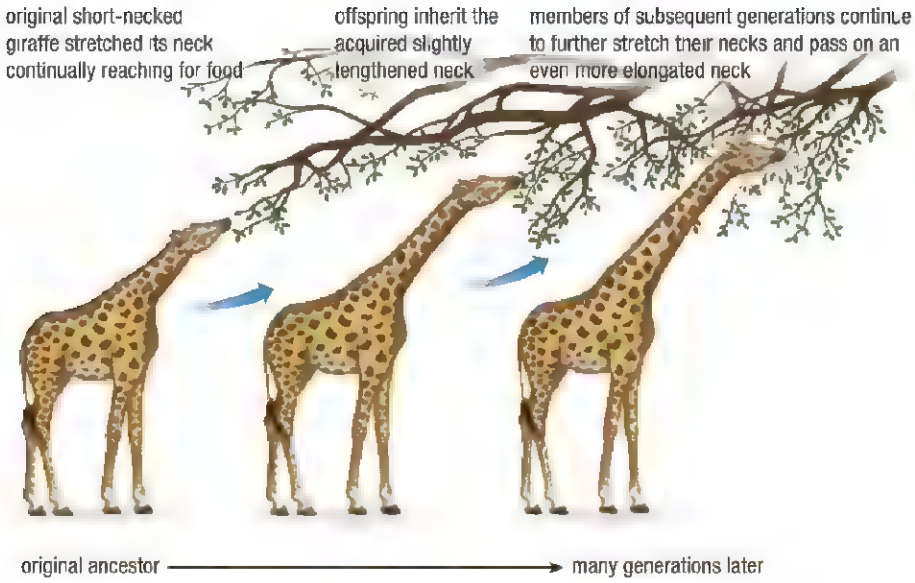


Figure 3 Lamarck's theory of evolution by the inheritance of acquired characteristics

Despite Lamarck's flawed theory, he did make a number of very significant contributions to our understanding of evolution. Lamarck proposed the following:

- All species evolve over time.
- A species evolves in response to its environment and becomes better adapted to that environment.
- Changes are passed on from generation to generation.

Lamarck's theory stimulated a great deal of scientific discussion, and his contributions provided a sound basis for the theory of evolution that would follow.

Patterns of Change

Even scientists who did not accept the idea that species could change were finding evidence that was extremely puzzling. They found some of this evidence in the form of **fossils**, which are preserved ancient remains of dead organisms. A minimum age of 10 000 years is sometimes used as a criterion for designating remains as a fossil.

fossil any ancient remains, impressions, or traces of an organism or traces of its activity that have been preserved in rocks or other mineral deposits in Earth's crust

Fossil Formation

Most fossils are hard impressions in solid rock. Many leave little doubt as to what they represent. No one could mistake a well-preserved fossil of *Knightia* (**Figure 4(a)**) for anything other than a fish or fail to recognize an obvious fossilized leaf (**Figure 4(b)**). It seemed self-evident to most scientists that such fossils had been formed by once-living organisms.

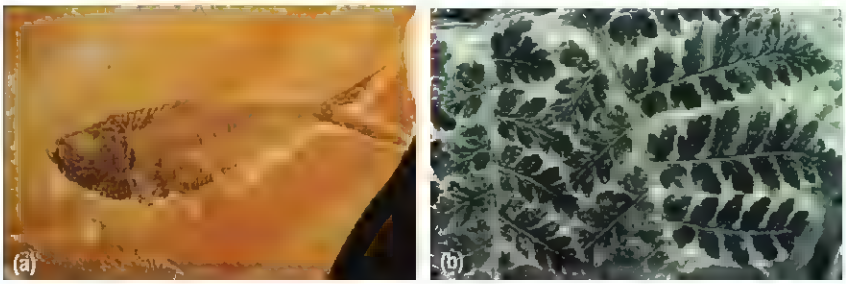
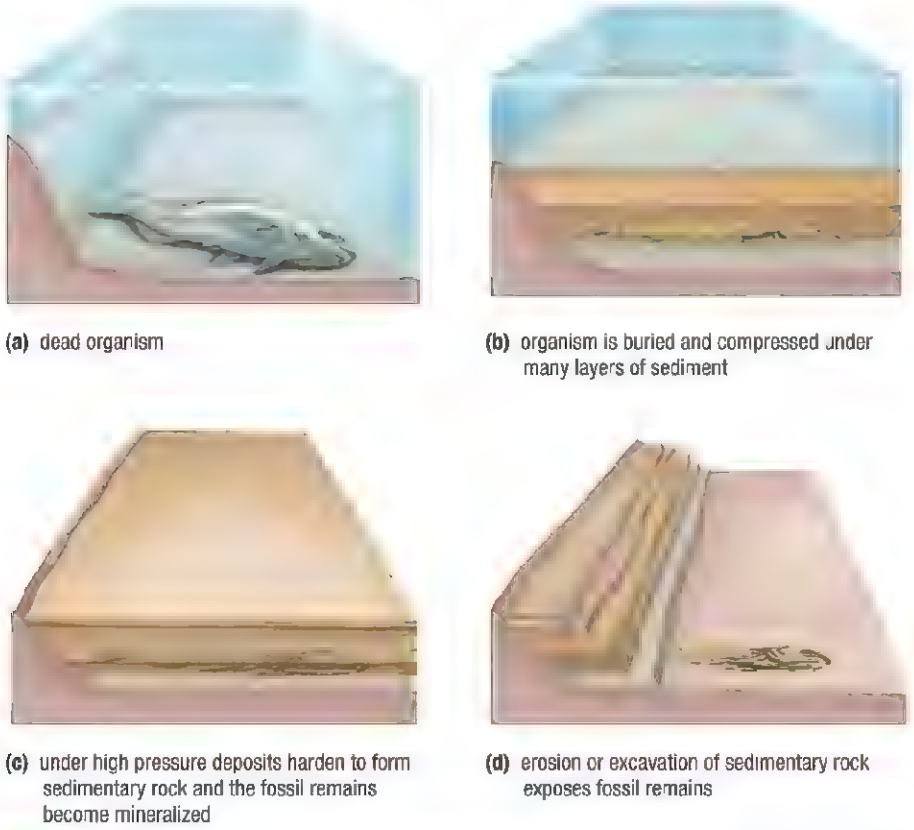


Figure 4 Fossils of both (a) *Knightia* and (b) leaves are extremely abundant in some rock formations.

Fossils are formed when the remains of a buried organism are gradually replaced by mineral deposits (**Figure 5**). After an organism dies, the body usually decomposes. However, if it sinks to the bottom of a body of water and is quickly buried by sediments, the resulting lack of oxygen can prevent decomposition. As sediments accumulate over time, the body becomes compressed, and very gradually chemical changes occur that result in the body being mineralized.



(a) dead organism

(b) organism is buried and compressed under many layers of sediment

(c) under high pressure deposits harden to form sedimentary rock and the fossil remains become mineralized

(d) erosion or excavation of sedimentary rock exposes fossil remains

Figure 5 (a) Most fossils form under water when an organism becomes buried in thick sediments. (b) In the absence of oxygen the organism does not decay. (c) Over time the chemical action and the pressure of the sediments change the organism into a mineralized form. (d) Fossils dating back millions and even billions of years may be found when such deposits are excavated.

Figure 6 Under the right conditions, footprints can become fossilized.

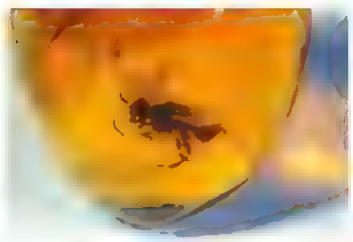


Figure 7 Organisms can be preserved in amber.

The necessary conditions for fossil formation are rare. When oxygen is present, bodies usually decompose too quickly to fossilize. Therefore, only organisms that die in low-oxygen locations will fossilize. Most often these are aquatic organisms living where sediment is continuously deposited. In addition, organisms with hard body parts such as shells, bones, and teeth are much more likely to be preserved than soft-bodied organisms. As a consequence, fossils of marine organisms with hard body parts, such as clams and snails, are very common, whereas fossils of land animals and plants are much less common. Dinosaur fossils are well known but are very rare in comparison to fossils of marine organisms. Fossils can also be formed from footprints, burrows, and even fecal remains. Sediments may fill in a footprint or burrow and then harden over time to create a fossil (**Figure 6**).

Organisms can also become trapped and preserved in amber—fossilized tree sap (**Figure 7**). Some of the most well-preserved fossils are formed when an entire organism becomes trapped in materials that preserve its chemical remains. Similarly, well-preserved fossils are formed when organisms are trapped in volcanic ash, ice formations such as permafrost, or acidic bogs.

Reading the Fossil Record

At first, scientists may have speculated that fossils were nothing more than recently living organisms that had become trapped in muddy deposits and then hardened over a relatively brief period of time. Perhaps fossils were just preserved plants and animals that were no more than a few hundred or a few thousand years old. This simple explanation was quickly contradicted by a number of observations that this idea could not explain:

- Many fossils appear to be of unusual and unknown organisms. There are fossils of thousands of species that are no longer living (**Figure 8**).
- There are no fossils of most living species.
- Fossils are often buried very deep within rock formations. Some are more than a kilometre below Earth's surface.
- Fossils are often found in unexpected locations. For example, fossils of sea life are found high in mountain formations and in present day deserts.

Figure 8 Fossils of dinosaurs, like this triceratops, leave little doubt that some fossil species are dramatically different than any species alive today.

Such observations were of great interest to early scientists. They became determined to develop a better understanding of how fossils formed and to understand what fossils could tell us about life in the past. The emerging science that studied fossil organisms to learn about prehistoric life was called **paleontology** (**Figure 9**).

paleontology the scientific investigation of prehistoric life through the study of fossils

Paleontologists used fossils to provide evidence that life had been very different in the past. Also around this time, the field of geology, the study of Earth's physical structure, was beginning to develop. Two prominent scientists, a paleontologist named Georges Cuvier and a geologist named Charles Lyell, began to provide a wealth of new evidence on how species and Earth might have changed over time.

Figure 9 Paleontologists study fossil plants and animals.

Catastrophism and Uniformitarianism

The famous paleontologist Georges Cuvier (1769–1832) conducted the first detailed studies of fossils. Cuvier noted the following

- Fossils of very simple organisms are found in all depths of fossil deposits.
- Fossils of more complex organisms are found only at shallower depths, in younger rock.
- Fossils in the shallower depths are more likely to resemble living species.
- Rock layers contain fossils of many species that do not occur in layers above or below them (**Figure 10**).

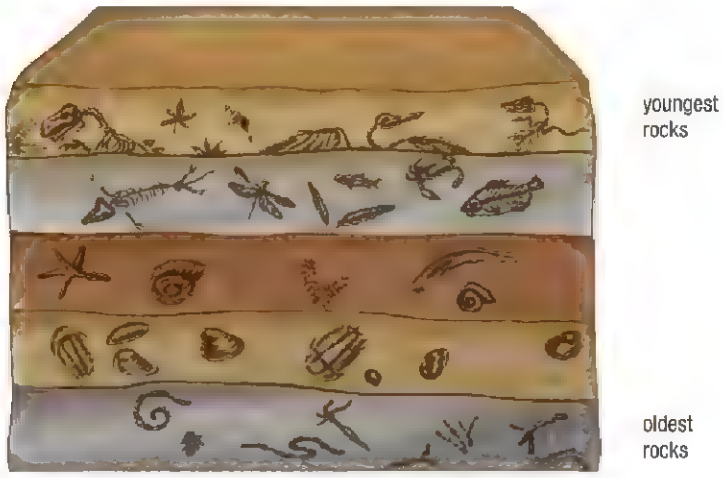


Figure 10 Cuvier noticed that all fossils from deeper layers were simpler than the more complex fossils above them.

Such observations offered strong support for the theory that life had evolved from simple to more complex forms over time. The oldest fossil deposits contain only simple life forms. More recent fossil deposits contain species that are both more complex and more similar to present living species.

Although the fossils Cuvier found showed a clear pattern of change from layer to layer, Cuvier believed that species themselves did not change. Instead, he proposed a theory of catastrophism. According to the theory of **catastrophism**, global catastrophes such as floods caused the widespread extinctions of species. These extinct species, some of which were fossilized, were then replaced by a newly created set of species. Cuvier's theory accounted for the different groups of species in each layer but did not adequately account for why each layer included progressively more complex forms.

catastrophism the theory that the pattern of fossils could be accounted for by a series of global catastrophes that wiped out most species on Earth

At about the same time that Cuvier was postulating catastrophism, Charles Lyell (1797–1875) was studying rocks and fossils and coming to the opposite conclusion. Considered the father of modern geology, Lyell revolutionized geology with his theory of uniformitarianism. In 1830, Lyell put forth the following principles of **uniformitarianism** in his now famous *Principles of Geology*:

uniformitarianism the theory that geological changes are slow and gradual and that natural laws and processes have not changed over time

- Earth has been changed by the same processes in the past that are occurring in the present.
- Geological change is slow and gradual rather than fast and catastrophic.
- Natural laws that influence these changes are constant and eternal, and they operated in the past with the same intensity as they do today.

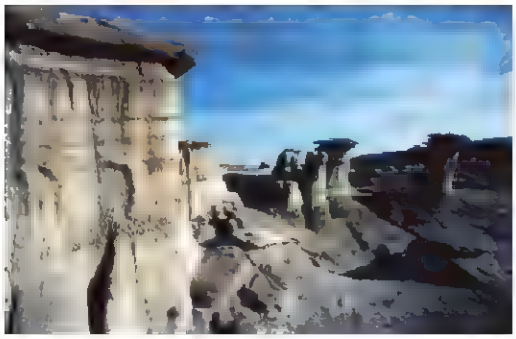


Figure 11 Millions of years are required for these layers of rock to accumulate and then to be slowly eroded away.

Lyell's ideas were radical. He was proposing that entire mountain ranges might have formed by extremely slow processes, and that deep gorges were the product of slow erosion (**Figure 11**). Lyell's theories directly challenged the belief in a very young Earth. If he was right, Earth was extremely old and life had had a very long time to undergo evolutionary change.

CAREER **LINK**

Paleontologist

Paleontologists are scientists who study ancient fossilized remains. Their work may require expeditions to different parts of the world. To learn more about becoming a paleontologist,

GO TO NELSON SCIENCE

CAREER **LINK**

Geologist

Geologists study the physical structure of Earth and how it has changed over time. To learn more about becoming a geologist,

GO TO NELSON SCIENCE

Research This

Paleontology and Geology

Skills: Researching, Evaluating, Communicating SKILLS HANDBOOK A5.1

The anatomist and paleontologist Baron Georges Cuvier and the geologist Sir Charles Lyell made substantial contributions to our early understanding of the history of life on Earth. In this research activity you and a partner will investigate the contributions of these individuals.

1. With your partner, use the Internet and other sources to research the lives of Cuvier and Lyell. When and where were they born? What were their social status, upbringing, and education? Take note of any unusual aspects of their lives.
2. Document Cuvier's and Lyell's contributions to paleontology and/or geology. Include their association with catastrophism and uniformitarianism.

A. Create a short biographical sketch of these two individuals. You may wish to present your sketch in the form of a personal profile on an Internet social networking or blog page. T/I C

B. In your sketch or profile, include a summary of their contributions to science. In what ways did they break new ground in our scientific understanding of Earth and life on Earth? T/I C

GO TO NELSON SCIENCE

The Stage Is Set

By the nineteenth century, scientific thought regarding the history of Earth and its life forms was undergoing substantial change. There was growing evidence that Earth was ancient and that species might be evolving. However, the mechanism for such change had yet to be adequately explained. Lamarck's contributions to ideas about evolution were significant, but his explanation for how life evolves was unsatisfactory. Unlike the debate over the age of Earth, however, the search for a mechanism for evolution would not have to wait for very long. It was to become the life's work of a young man named Charles Darwin (**Figure 12**).

Figure 12 Charles Darwin

7.2 Summary

- By the eighteenth century, scientists were beginning to gather evidence supporting the theory that life had changed over time.
- Lamarck was the first scientist to recognize that species evolved in response to their environment, but his hypothesis of how species evolved has proven to be incorrect.
- Fossils provide compelling evidence that species living in the past were different from those living in the present.
- Fossils show that organisms become increasingly complex over time, with the most complex organisms being found in only more recent fossil deposits.
- Cuvier proposed that species did not change but were eliminated by catastrophic events, only to be replaced by newly created forms.
- Lyell proposed that Earth's geologic features can be explained by very slow changes occurring over very long periods of time.

7.2 Questions

1. (a) Why was Buffon puzzled by pig's toes?
   (b) How did he explain them? K/U
2. What explanation did Lamarck propose for how species had changed over time? K/U
3. What role did Lamarck believe the environment played in evolution? K/U
4. Use Lamarck's theory to explain the evolution of running speed in cheetahs. K/U A
5. Based on Lamarck's theory of evolution, what could you do to ensure your children were born with enhanced musical ability? K/U A
6. Illustrate the process of fossil formation using labelled sketches. K/U C
7. What do the following characteristics of fossils reveal about the history of life on Earth? K/U A
   (a) Some fossils of marine organisms are discovered at high elevations in mountains.
   (b) Most fossils are of species that are no longer living.
   (c) Most living organisms are not found in the fossil record.
   (d) Most fossils are of marine organisms.
   (e) The oldest fossil deposits contain only simple organisms. More recent deposits contain both simple and complex fossils.
8. How did the theory of catastrophism account for patterns seen in the fossil record? K/U
9. How did the theory of uniformitarianism account for patterns seen in geology? K/U
10. How might it be possible for fossils to provide evidence about the behaviour of an organism? A
11. There is fossil evidence supporting the hypothesis that some dinosaurs exhibited social behaviour. In what ways do you speculate dinosaurs might have been social? What sort of fossil evidence do you think might support such a hypothesis? Use the Internet and other sources to investigate these questions and report your findings to the class. T/I A C
12. Imagine you were asked to excavate fossils from deposits near the top of the Grand Canyon and near the bottom. Predict any pattern you would expect to find in the fossils. T/I A
13. The most famous fossil deposit in Canada is the Burgess Shale. Use the Internet and other sources to find answers to the following questions: T/I A C
    (a) Where is the Burgess Shale located?
    (b) When and by whom was it discovered?
    (c) What is the age of the fossils in the deposit?
    (d) What makes the deposit of special interest?
14. There are many rock formations containing fossil deposits throughout Ontario. Find out about any such formations in your area and consider seeking appropriate permission and organizing a fossil-collecting trip. T/I

GO TO NELSON SCIENCE

7.3 — *Biology* JOURNAL —

Voyage of the HMS *Beagle*

ABSTRACT

Charles Darwin's five-year voyage aboard the HMS *Beagle* stimulated his curiosity and set him on the path to great discovery. Darwin's keen powers of observation, exhaustive collections, and new findings provided a wealth of evidence on the origin of species. Darwin was puzzled because many of his observations could not be explained by his previously held beliefs. Darwin would devote much of his life to developing a theory that could account for his many observations.

Introduction

In December 1831, Charles Darwin set sail on the HMS *Beagle* and began a five-year voyage of discovery. The young Darwin, age 22, had been recommended for the voyage by his former professor, John Henslow, who considered Darwin an exceptional naturalist.

The primary mission of the *Beagle* was to survey and map the coastal waters of South America for the British Navy. Darwin was to observe, record, and collect specimens of rocks, minerals, plants, and animals. His supplies included specimen jars and preservative, a microscope, binoculars, notebooks, a rifle, and a book given to him by Henslow—the first volume of Lyell's *Principles of Geology*

What Darwin Saw

As the crew of the *Beagle* was conducting surveys along the east and west coasts of South America, Darwin hired guides and travelled inland to explore, often for weeks at a time (**Figure 1**). Darwin was impressed by the diversity of life he encountered, the grandeur of the rich tropical rainforests, and the geographic features of the landscape. He was keen to document everything he saw. Darwin was a meticulous observer and painstaking collector. During the voyage he gathered thousands of specimens and filled notebooks with more than 4000 pages of detailed observations.

While in Patagonia, Darwin made some important discoveries including fossils of giant *Glyptodon* (**Figure 2**) and *Megatherium*. Darwin would later find out that these specimens resembled the much smaller modern armadillos and sloths, respectively. Darwin noted that modern and extinct animals that resemble each other seemed to share similar geographical distributions. In this case, like their fossil relatives, modern-day armadillos and sloths are both found in South America.

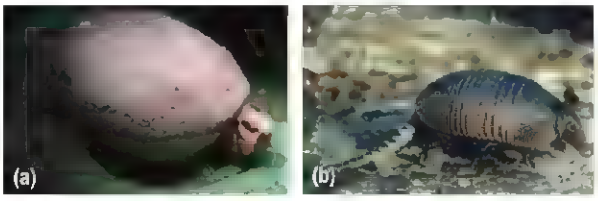


Figure 2 (a) The fossil *Glyptodon* resembled (b) the present-day armadillo, except that the *Glyptodon* was almost 200 kg heavier.

Figure 1 Darwin spent five years on the HMS *Beagle*. The ship was 27.5 m long and carried 74 people. Darwin's cabin was so small that he had to remove a drawer from the end of his bunk to make room for his feet when he lay down.

Darwin also discovered fossils of marine organisms high in the Andes Mountains. Later, following a severe earthquake, he was informed that a section of coastline had risen 3 m out of the water. This evidence supported Lyell's theory that such events could, over millions of years, account for large-scale changes like the formation of mountain ranges. By the time Darwin left South America, he was becoming increasingly convinced that Earth was dynamic and changing.

The Galapagos Islands

The most famous of Darwin's observations were on the Galapagos Islands, lying approximately 1000 km off the west coast of South America. This small isolated archipelago is made up of 18 islands that were formed from volcanoes that rose up from the ocean floor.

Upon his arrival Darwin was immediately struck by the unusual and unique flora and fauna that inhabited the islands. Among the most unusual species were birds such as the nesting boobies, with no fear of humans, iguanas that could dive underwater to feed on seaweed, and giant land tortoises (**Figure 3**). Oddly, many species bore a striking resemblance to species he had observed on the continent of South America, even though they lived in entirely different habitats.

Figure 3 (a) The Galapagos marine iguana and (b) a species of Galapagos tortoise

As he went about collecting specimens, it did not occur to Darwin that neighbouring islands, often within sight of each other, might be home to entirely different species. Only later would he learn from experts that many of the specimens he had assumed were just varieties of a single species were different species entirely, including the 13 species of Darwin's finches that are now famous.

Perhaps as surprising were the species that were absent from the Galapagos. There was not a single native species of amphibian or large land mammal in the entire Galapagos, even though some of these islands were over 100 km in length. Darwin realized that only species that could have arrived by air or water lived in the Galapagos. Insects, birds, plants, and reptiles could have arrived by air or water. Amphibians perish in salt water, and no large terrestrial mammal can survive for long without fresh water. It seemed the islands had been populated by species that had arrived from elsewhere. However, most of these species only *resembled* species in mainland South America; they did not live there.

Darwin's Return

Darwin left England believing that species were immutable, but he returned five years later with many doubts. Darwin was an individual of extraordinary determination. He would spend the next 20 years of his life formulating his theory of evolution and unravelling what he referred to as "that mystery of mysteries." The influence of the *Beagle* voyage is captured in Darwin's own journal entry of 1837: "Had been greatly struck . . . on character of S. American fossils—& species on Galapagos Archipelago. — These facts origin (especially latter) of all my views."

Further Reading

Darwin, Charles. (1839). *Voyage of the "Beagle."* Available online at The Complete Work of Charles Darwin Online.

Darwin, Charles. (1835). *Galapagos notebook.* Available online at The Complete Work of Charles Darwin Online.

Stewart, P.D. (2007). *Galapagos: The islands that changed the world.* New Haven: Yale University Press.

GO TO NELSON SCIENCE

7.3 Questions

1. What qualities of a good scientist did Darwin display on the voyage? K/U
2. Describe Darwin's key observations regarding the distribution of fossils. K/U
3. What did the change in coastline following an earthquake lead Darwin to believe?
4. Darwin was surprised by the species he found on the Galapagos Islands. K/U T/I A
   (a) What other species did they remind him of?
   (b) What is the connection between the types of native animals on the Galapagos and their ability to cross the open ocean?
5. In a small group of two or three students, use the Internet and other sources to research the following: T/I A C
   (a) Examine Darwin's childhood and formal education.
   (b) Find out what circumstances led to Darwin's selection for participation in the voyage and his acceptance.
   (c) Describe the life history of at least one species of Galapagos wildlife.
   (d) Outline some of Darwin's other scientific findings from the voyage, including his investigation of coral reefs.
   (e) Describe Darwin's work ethic and approach to science. Did Darwin conduct any experiments of his own? Did he rely on the opinions of others?

GO TO NELSON SCIENCE

7.4 The Evidence for Evolution

Charles Darwin returned to England in 1836, ending his voyage on the HMS *Beagle*. Darwin had spent five years making countless observations and gathering thousands of specimens. He was now filled with new ideas and questions about species.

In July of 1837 Darwin began writing his first notebook on what he called the "transmutation of species." It would mark the beginning of Darwin's far-reaching investigations on the evolution of species. In a letter to his friend Sir Joseph Hooker in 1844, Darwin described his approach: "I was so struck . . . that I determined to collect blindly every sort of fact, which could bear [in] any way on what are species. I have read heaps of agricultural and horticultural books, and have never ceased col lecting facts." In the years that followed, Darwin stayed true to his words, continuing to consult experts, conduct numerous experiments, and spend long hours contemplating his findings.

This section will present the many forms of evidence that convinced Darwin of the evolution of species and enabled him to formulate his theory.

Biogeography

biogeography the scientific study of the geographic distribution of organisms based on both living species and fossils

Some of the most compelling evidence for evolution comes from **biogeography**, the observed geographic patterns of distribution of species. Darwin's observations of both living and fossilized species during the voyage of the *Beagle* laid the foundation for this new science. Darwin was particularly surprised by the unusual assortment of species he found on the Galapagos Islands. Though not witnessed by Darwin, other remote islands, including New Zealand and Hawaii, held odd collections of very similar species (**Figure 1**).

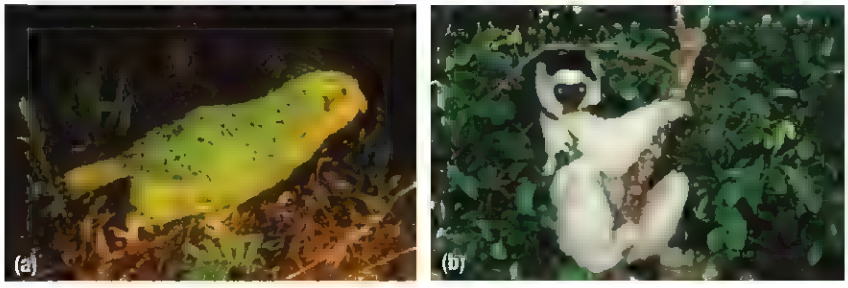


Figure 1 (a) The New Zealand kakapo is a giant nocturnal parrot and the world's largest and only flightless parrot. It is critically endangered. (b) All 99 lemur species, including this sifaka, live only on the island of Madagascar, but there are lemur fossils in India.

Figure 2 Many species, such as this Galapagos tortoise, that live on remote islands show no fear of humans.

Remote islands are also associated with unusual examples of animal behaviour. Many species are unusually fearless (**Figure 2**). Such behaviour surprised Darwin and is immediately apparent to any present-day tourist visiting these remote environments. Birds may land on your head, iguanas will allow themselves to be picked up, and sea lions are content to have you sit next to them on the beach. Darwin believed that this lack of fear of people could also be accounted for by evolution. Perhaps these species, living and evolving in a location with no natural predators, had lost their instinctive fear.

WEB LINK

To learn more about the fascinating species that live on the Galapagos and other remote islands,

GO TO NELSON SCIENCE

Darwin's Hypotheses

Darwin realized that the patterns he had observed regarding the distribution of species, both living and extinct, were evidence that species might have evolved. He hypothesized that remote oceanic islands became populated by species that arrived by water or air. After the species became established, many evolved into new species over time.

Darwin considered evolution to be the best explanation for why isolated islands had many species that were found nowhere else, and why these species bore a resemblance to species on the nearest continental land mass. **Table 1** lists some key observations regarding the species inhabiting the Galapagos Islands. Each observation is matched with Darwin's corresponding hypothesis for all remote islands, based on the theory that species evolve.

Table 1 Species on Remote Islands

Observations from the Galapagos Islands	Darwin's hypotheses regarding remote islands
many species of plants, birds, insects, and, in some cases, reptiles	Only these kinds of organisms are able to reach remote islands by crossing large expanses of open ocean.
no native amphibians and very few land mammals	Amphibians and most mammals are unable to cross open ocean and will not be found on remote islands.
many unique species found nowhere else on Earth	Over time, ancestral species have evolved into new geographically isolated species.
unique species most closely resemble species on the nearest continental land mass	Unique species are descendants of ancestral species from the nearest continental land masses and will exhibit some similarities.

Testing Darwin's Hypotheses

Darwin's hypotheses were tentative explanations for his observations. If correct, these hypotheses would apply to similar situations. The strength of any hypothesis is determined by how well it is supported by future tests and observations. In this case, the Hawaiian islands provide an excellent test case of Darwin's hypotheses. Like the Galapagos, the Hawaiian islands were formed from volcanoes that rose directly from the ocean floor (**Figure 3**). They have a wide range of habitats and have never been connected to any other land mass.

Figure 3 The Galapagos and Hawaiian islands were formed by volcanoes that rose from the bottom of the Pacific Ocean.

An examination of the native species of Hawaii supports Darwin's hypotheses. There are no native amphibians or mammals, with the exception of bats and sea lions. There are many species of unique plants, birds, and insects. Unlike the Galapagos, however, there are no native terrestrial reptiles. The only Hawaiian reptiles are marine species: a sea snake and five species of sea turtles. This difference can be accounted for by the fact that the Galapagos lie within 1000 km of the coast of South America, whereas the Hawaiian islands are much more remote—more than 4000 km from the coast of North America. No land reptile could be expected to survive such a long ocean crossing.

In testing a hypothesis, it is important to consider alternative explanations that might account for your findings. What if remote islands lack certain groups of organisms because these species are not able to live in such settings? Perhaps mammals and amphibians, for example, simply cannot survive on large oceanic islands. This alternative hypothesis has been put to the test when non-native species are introduced to islands. Introduced species have not only thrived in these new environments, but have also had a devastating impact on many native species. Rats, dogs, and pigs have wreaked havoc on native bird and tortoise populations. They eat the eggs and young of tortoises and ground-nesting bird species, which exhibit no fear or defensive behaviours. The impacts have been particularly damaging in Hawaii, where an estimated 271 species have become extinct since the arrival of Europeans in 1778. The black mamo (*Drepanis funerea*), for example, a species of honeycreeper, became extinct in about 1907. Of the original 41 species of Hawaiian honeycreeper, 17 are probably extinct, 14 are endangered, and only 3 species have large healthy populations (**Figure 4**). Therefore, mammals and amphibians are indeed able to survive on remote islands once they are introduced, and we cannot accept the alternative hypothesis. To date, Darwin's hypotheses have been supported by the observations of life on all remote islands.

Figure 4 The black mamo was extinct by 1907.

Research This

Investigate Darwin's Research

Skills: Researching, Analyzing, Evaluating

SKILLS HANDBOOK A5.1

Darwin was aware that not all seeds could have been carried to remote islands by the wind or birds. He hypothesized that some seeds must have reached the islands by floating in ocean currents. If his hypothesis was correct, the seeds must have been able to withstand exposure to salt water for days or weeks on end.

1. Find out how Darwin attempted to test his hypothesis. Read Darwin's own writings in which he describes his experimental results.
2. Use the Internet and other sources to find information regarding Darwin's hypothesis. Is there good evidence that some seeds can withstand a long time at sea?

A. Did Darwin's experiments support or refute his hypothesis? T/I A

B. Many historians of science consider Darwin to be extraordinarily thorough and meticulous. Did your research support this characterization? T/I A

C. Based on your research, does it seem reasonable to think that some seeds might have reached remote islands by drifting there on ocean currents? A

D. How else can seeds be naturally transported to remote islands? A

GO TO NELSON SCIENCE

Homologous and Analogous Features

If all living things are related to each other, as the theory of evolution suggests, then we should expect to find evidence for such relationships by examining their anatomy. Darwin and others were struck by the numerous instances in which similar structures of two organisms could have entirely different functions (**Figure 5**). These **homologous features** puzzled Darwin, who wrote: "What can be more curious than that the hand of a man, formed for grasping, that of a mole for digging, the leg of the horse, the paddle of the porpoise, and the wing of the bat, should all be constructed on the same pattern, and should include the same bones, in the same relative positions?" Imagine an engineer being asked to design a robotic hand, a canoe paddle, and an aircraft wing, and choosing the same internal frame design for each device!

homologous feature a structure with a common evolutionary origin that may serve different functions in modern species (for example, bat wing and human arm)

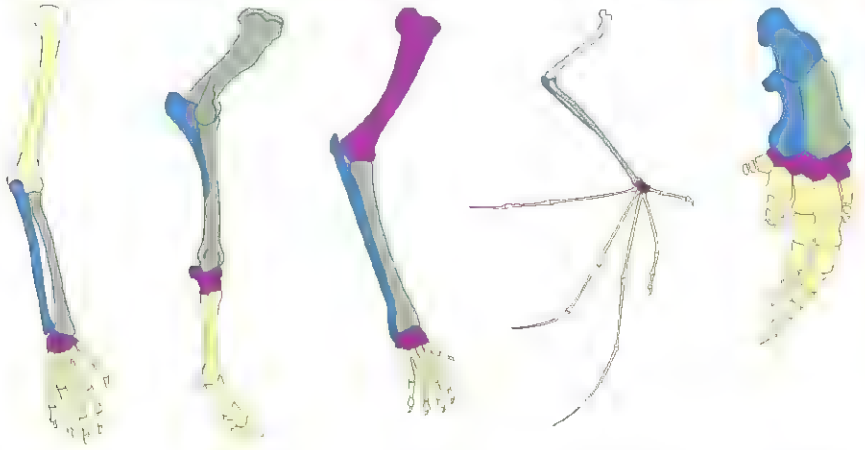


Figure 5 The forelimbs of these organisms are each adapted to carry out very different functions, yet they all possess very similar bone structure.

It struck Darwin as unreasonable to think that finger bones would serve any useful purpose inside the stiff flipper of a whale. He also wondered why almost all mammals would have precisely 28 skull bones and 7 neck bones, regardless of the size of their skull or length of their necks. If species had been created in their present forms, why would the skull of a whale have the same number of bones as the skull of a mouse, and why would the giraffe not be given more neck bones than mammals with the shortest necks? Indeed, why were the bones in all mammals, including bats, whales, horses, and humans, so similar in number and arrangement (**Figure 6**, next page)?

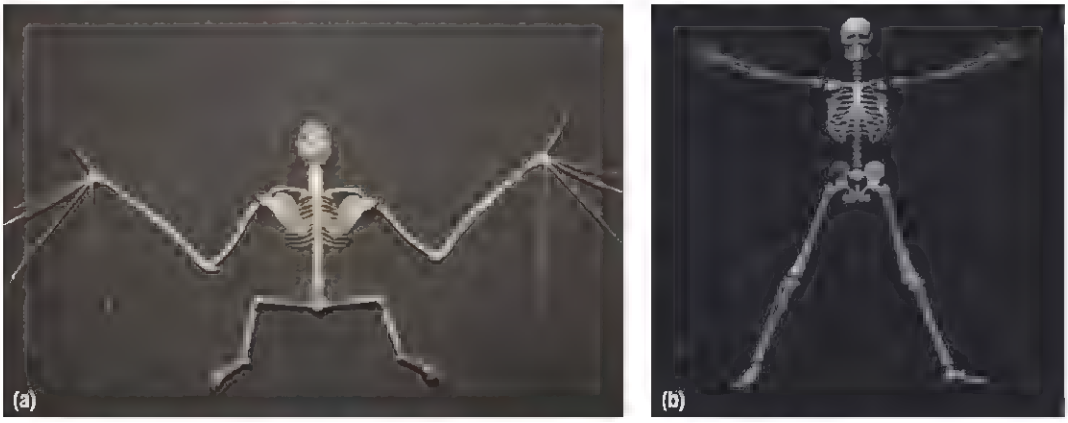


Figure 6 All mammals have an almost identical number and arrangement of bones. (a) This tiny bat skeleton is very similar in many respects to that of (b) a human.

Although Darwin had no understanding of chromosomes and genes, he knew that many traits were inherited from generation to generation. Darwin was also aware that artificial breeding of animals and plants could, over many generations, produce dramatic results. For example, he knew that dog skeletons had changed through the efforts of breeders. Darwin concluded that the homologous features he observed could be explained by evolution. Closely related species had homologous features because they shared a common ancestor. Over time original structures were modified as each species evolved.

Closely related species share homologous developmental processes and patterns as well. In early developmental stages, the embryos of all vertebrates, including humans, chickens, and fish, possess a short bony tail (**Figure 7**). Human embryos also have gill slits even though, by the time we are born, we do not have gills.

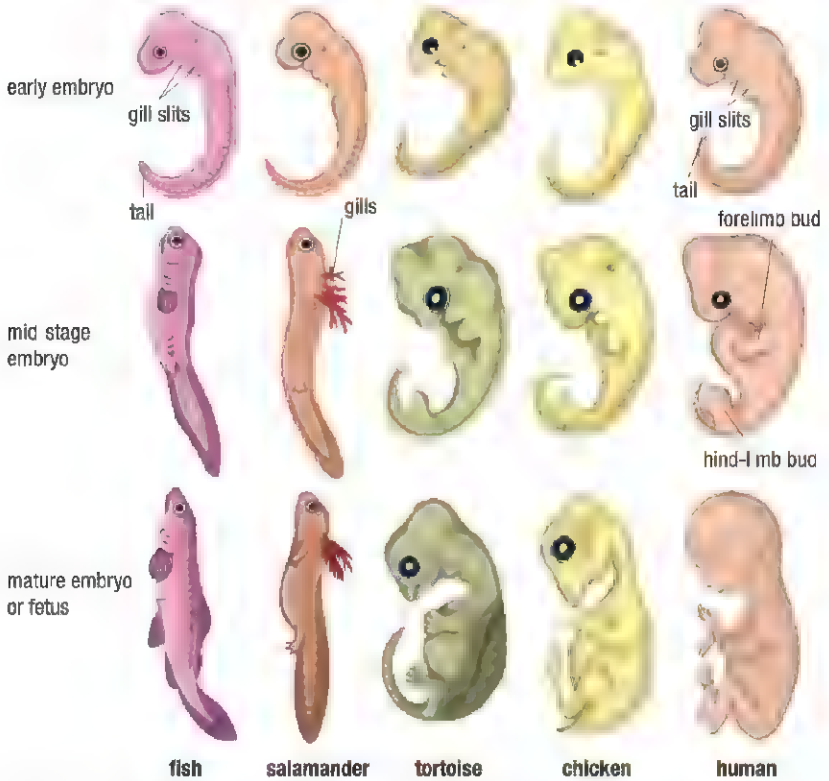


Figure 7 The early embryos of all vertebrates share many homologous features, including tails and gill slits

analogous feature a structure that performs the same function as another but is not similar in origin or anatomical structure; for example, bird and insect wings

Evolutionary relationships can also account for the observed differences in the structure of **analogous features**—features that perform similar functions. For example, the eyes and wings of flying insects serve the same function as the eyes and wings of flying birds yet are completely different in structure. Insects and birds are only distantly related and have evolved these features quite independently of each other.

Vestigial Features and Anatomical Oddities

vestigial feature a rudimentary and non-functioning, or only marginally functioning, structure that is homologous to a fully functioning structure in closely related species

What would you say if you discovered a fish with eye sockets but no eyes, or a running animal with toes that never touch the ground? These species would be displaying **vestigial features**—features that no longer serve the function they do in similar species. Several species of cave fish in the family Amblyopsidae live in perpetual darkness (**Figure 8**). They have no eyes or tiny vestigial eyes. A number of mammals, including pigs, horses, and dogs, possess vestigial toes that serve no useful purpose (**Figure 9**).

Figure 8 Some species of cave-dwelling fish have vestigial eyes or no longer develop eyes at all.

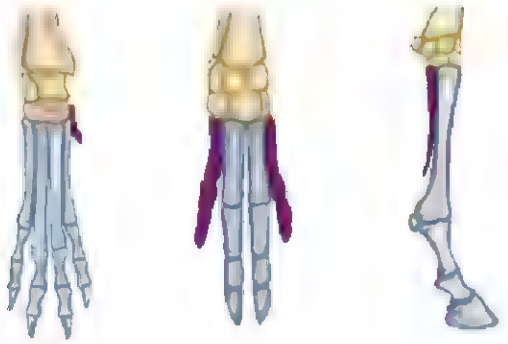


Figure 9 (a) Dogs have a vestigial toe, or "dew claw," on each front limb. The toe serves no useful function. (b) Pigs have two well developed toes and two vestigial toes that hang behind them. (c) Horses have one greatly enlarged toe. The others are vestigial or missing entirely. Vestigial toes are shown in purple.

There are many striking examples of vestigial features and anatomical oddities. For example, the upland goose and frigate bird have webbed feet but never enter the water. Some large snakes and whales have vestigial hip bones, which are homologous to the hip bones that support the hind limbs of other vertebrates (**Figure 10**).

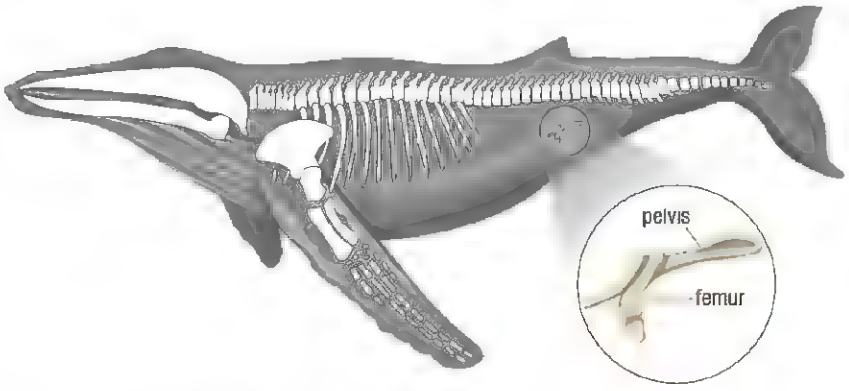


Figure 10 Many species of large whales have vestigial hip bones.

A fascinating example of an anatomical oddity is found in the nervous system of vertebrates. In fish, a particular nerve exits the brain and follows a short and direct pathway to a gill located close to the heart. In all mammals, the same nerve exits the brain, but it follows an indirect path. The nerve passes close to the heart, but then travels back up the neck and enters the larynx, or voice box. In giraffes, the trip is

quite lengthy: the nerve leaves the brain, travels the full length of the neck, down to the heart and back again, before entering the larynx. The distance from a giraffe's brain to its larynx is a few centimetres, but the pathway travelled is more than 4 m!

Darwin recognized that such features were highly suggestive of an evolutionary past. Vestigial features could be explained as evolutionary baggage—features that, in an ancestor, had served a useful purpose, but had become useless or greatly distorted as the species evolved.

Humans also possess numerous vestigial features. You may have experienced goosebumps in a cool breeze or when you were watching a scary movie. Humans, like most mammals, have body hair. Each hair is attached below the surface of the skin to a tiny muscle. Goosebumps are the result of these tiny muscles contracting and lifting up the hair. For mammals with thick hair, this action serves two functions: in response to cold temperatures, it increases the insulation value of the hair, making the animal warmer, and, in response to a threat, it makes the mammal look larger. For a deer on a cold winter day, this is a way of staying warm. For a cat confronted by a large dog, this is a way of looking large and menacing. For humans, raising our hair does nothing to keep us warm and certainly does not make us look any larger.

WEB LINK

To learn more about human vestigial features,

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Competition within Populations

The anatomical features of different species, biogeography, and the fossil record provided Darwin with evidence that species had changed over time and that species appeared to share a common ancestry. Breeders of domesticated animals and plants repeatedly demonstrated that species could change by selecting individuals with favoured traits to be the parents of each new generation. Darwin wondered if nature, like human breeders, might be able to favour certain individuals in a population over others. He found the answer in October of 1838 while reading a mathematics paper on populations, *Essay on the Principle of Population*, written by the Reverend Thomas Malthus.

In his essay, Malthus showed that all populations were limited in size by their environment—and in particular their food supply. Whatever the conditions, populations could not continue to grow indefinitely. Darwin was struck by the implications this had for individuals within populations. Many species produce large numbers of offspring, but not all survive (**Figure 11**). There is a limit to the size of the population that an environment can support. The result is competition for survival between members of the same species.

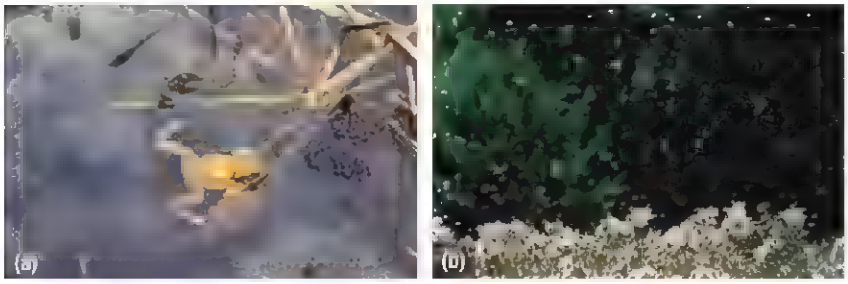


Figure 11 (a) Frogs and toads produce hundreds of eggs, but few will reach maturity. (b) Similarly, many plants produce thousand of seeds.

Competition between individuals of the same species is intense because they are vying for the same resources. Consider a population of 1000 robins that returns to Ontario in the spring. These 1000 robins form breeding pairs that may lay two or three batches of eggs each summer. If they all hatched and survived, the robin population would jump from 1000 in the spring to more than 5000 by the end of the summer. Of these 5000 robins, only about 1000 will return the next spring. Under these conditions, only one out of every five robins survive each year.

Darwin wondered if the environment might be favouring certain individuals in this struggle for survival.

Mini Investigation

The Elephant Problem

Skills: Researching, Performing, Analyzing, Evaluating

SKILLS HANDBOOK A2.1

Species that produce large numbers of offspring experience intense competition. Darwin wondered if this applied to even slow-breeding populations, such as elephants. His question is known as "the elephant problem." In this activity you will compare the breeding potential of different species and the population sizes that would result if there was unlimited growth (**Figure 12**).

Figure 12 (a) A starfish can produce 2 billion offspring per year whereas (b) a female elephant has one offspring every four or more years.

Table 2 includes sample estimates of changes in population size for two different situations: under natural conditions with competition and under ideal conditions with no competition based on the assumption that all offspring live and reproduce. For example, in the case of elephants, the latter value is based on the assumption that all elephants live to be 90 years old and each female has six offspring in her lifetime.

1. Examine Table 2 and compare the initial population sizes with the estimated final population sizes under natural conditions. Note that under natural conditions populations often remain relatively stable over modest periods of time. Calculate the percentage change in the population size.
2. Compare the initial population sizes with the final population sizes under ideal conditions where there is no competition. Calculate the percentage change in the population size.

A. What might cause a change in population size under natural conditions? T/I

B. How do these data provide evidence that species do not live under ideal conditions? T/I

C. Choose one species from Table 2 and conduct online research to determine some of the resources this species requires to survive (such as types of food, space, and shelter). Which of these resources do you think would cause the greatest degree of competition between individuals of the same species? T/I A

D. Imagine a dog breeder who makes a living selling champion show dogs. Do think the breeder would attempt to produce the maximum number of pups each year? What might be the advantages and disadvantages of doing so? T/I A

Table 2 Population Potential

Species	Initial population	Elapsed time	Final population under natural conditions	Final population under ideal conditions
elephant	100	300 years	84	24 300
robin	100	10 years	120	3 300 000
deer mouse	100	10 years	96	320 000 000
starfish*	2	5 years	2	10 000 000 000

*Female starfish of some species can produce 2 billion eggs per year.

GO TO NELSON SCIENCE

Assessing the Evidence

Darwin spent more than 20 years gathering and examining evidence on the question of whether species had evolved or had been created in their present forms. In the end he was convinced that the preponderance of evidence supported the evolution of species, but he also knew that his ideas would be controversial and conflict with the common religious beliefs of society. Many other scientists, including Linnaeus, Lamarck, and Darwin's own grandfather, believed species were not immutable. What set Darwin apart were the great insights he had gained while amassing the evidence. Darwin believed not only that species *had* evolved, but also that his theory could explain *how* they evolved. In the next section you will learn the circumstances leading to Darwin's publication of *On the Origin of Species* and be introduced to his famous and elegant theory.

UNIT TASK BOOKMARK

As you work on your Unit Task consider how evidence of evolutionary change can provide valuable information to scientists.

7.4 Summary

- Biogeography provides compelling evidence that remote islands are populated by species that evolved from species that had travelled from the closest major land mass.
- Patterns in embryonic development provide evidence of the evolutionary relationships between species.
- The structures of numerous anatomical features provide strong evidence that they have evolved from an original, homologous structure.
- Vestigial features are rudimentary structures that once performed important functions in ancestral species.
- All species produce more offspring than can survive to reproduce. This results in competition for resources between members of the same species.

7.4 Questions

1. Which of the following would you expect to find on remote islands? Explain your reasoning. K/U T/I
   (a) a variety of hummingbirds OR a variety of larger seed-eating birds
   (b) large lizards OR large mammals
   (c) some species that are genetically similar OR most species that are genetically very distinct
   (d) species found nowhere else on Earth OR species that are also found on other remote islands
2. The coqui frog, *Eleutherdactylus coqui*, was accidentally introduced to Hawaii, where it has no natural predators, in 1988. The population has risen dramatically, and the frogs now pose a threat to native species, particularly insects and spiders. If these frogs are so successful, why are there no native frog species on these large islands? T/I A
3. The brown tree snake, *Boiga irregularis*, was introduced to the remote Pacific island of Guam sometime shortly after World War II. Use the Internet and other sources to answer the following: T/I A
   (a) What native species have been lost or threatened by this snake?
   (b) How might the loss of these species influence the entire ecosystem on the island?
   (c) How might an understanding of evolution enable scientists to predict which species might be most vulnerable to invasive species?
4. Which of the following pairs represent homologous features and which represent analogous features? Explain your answers. A
   (a) the claw of a lobster and the hand of an ape
   (b) the wing of a bat and the wing of a bird
   (c) the eyes of a fly and the eyes of a hawk
   (d) the tusks of an elephant and the teeth of a mouse
   (e) the webbed feet of an otter and the fins of a fish
5. Explain how the bones within dolphin flippers, arranged in a pattern of five toes, provide evidence of evolutionary change. K/U A
6. Describe the evidence of evolution revealed by the embryonic development of different species. K/U
7. For each of the following vestigial features, state the likely original function of the structure and suggest a reason why it may have become vestigial: K/U A
   (a) the muscles and hairs that cause goosebumps in humans
   (b) short wing "stubs" in some insects such as earwigs
   (c) webbed feet in frigate birds that never enter the water
   (d) rudimentary hip bones in some large snake species
8. Explain how Darwin knew that competition occurs between individuals of the same species. Include a numerical example to illustrate your answer. K/U T/I

GO TO NELSON SCIENCE

7.5 On the Origin of Species

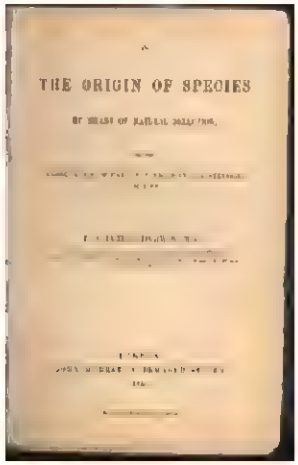


Figure 1 The first edition of Darwin's *On the Origin of Species*

WEB LINK

To learn more about Alfred Russell Wallace and his many contributions,

GO TO NELSON SCIENCE

Darwin's *On the Origin of Species* was published in 1859 (**Figure 1**). This book not only described convincing evidence that species *had* evolved, it also proposed a theory of *how* species evolve. Darwin had formulated his theory much earlier. In 1844, Darwin wrote to his friend Sir Joseph Hooker, declaring:

> "At last gleams of light have come, and I am almost convinced (quite contrary to opinion I started with) that species are not (it is like confessing a murder) immutable. . . . I think I have found out . . . the simple way by which species become exquisitely adapted to various ends."

In the same year, Darwin prepared a 231-page outline of his theory and gave it to his wife, with instructions that it be published should he die unexpectedly.

Aware that any theory of evolution would be controversial and rigorously challenged, Darwin continued to gather evidence and look for flaws and weaknesses in his own reasoning. By June 1858, when he had written a quarter of a million words, he received a fateful letter from a brilliant young biologist working in Malaysia. In the letter, Alfred Russell Wallace outlined his own theory of how species evolved. His theory was almost a perfect match to Darwin's.

The young Wallace, with little evidence, was anxious to publish a theory that he had thought about for only a few days. Darwin, having spent 20 years amassing evidence and developing the same theory, had been unwilling to publish. Charles Lyell and Hooker convinced Darwin to submit a paper along with Wallace's at a meeting of the Linnean Society of London on July 1, 1858. The papers were of interest to scientists of the Linnean Society but went unnoticed by the public. A year and a half later, Darwin published a detailed account of his theory in a 502-page book entitled *On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life*. The book sold out on the first day.

The Theory of Evolution by Natural Selection

natural selection the way in which nature favours the reproductive success of some individuals within a population over others

Although Darwin had been hesitant to publish, he was extremely confident in his theory that species had evolved by a process he called natural selection. Darwin described **natural selection** as the way in which the environment, or nature, favours the reproductive success of certain individuals over others. Evolution was simply the result of natural selection occurring over many generations. Darwin's reasoning is illustrated in **Figure 2**.

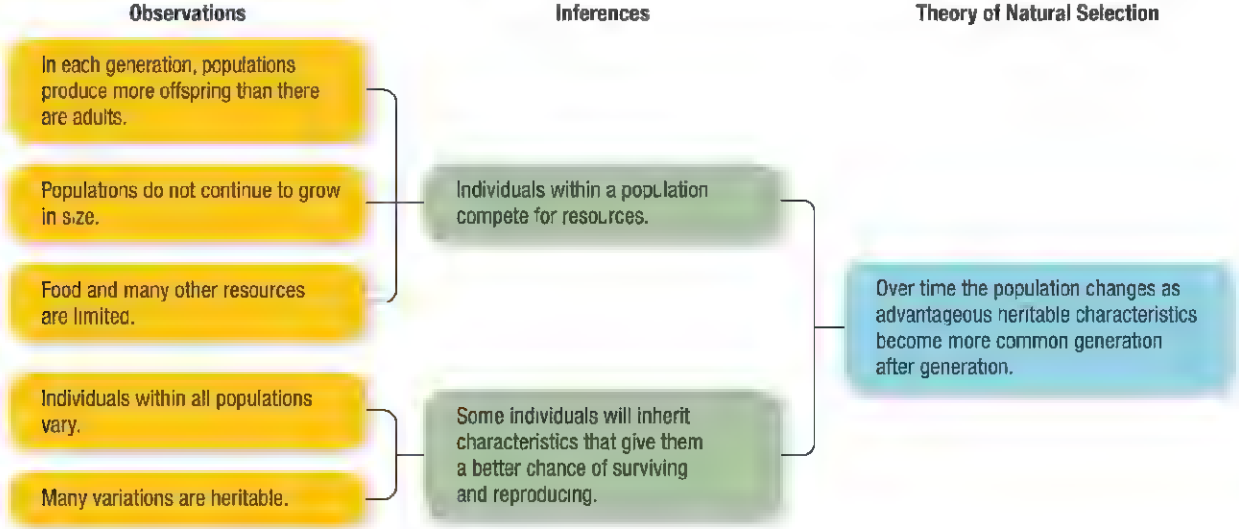


Figure 2 Darwin's theory of evolution by natural selection was powerful because it was based on five key observations that were well established and undeniable. Darwin realized that together, they gave rise to two logical inferences and provided a mechanism for evolution.

Darwin's key observations were undeniable: all healthy populations produced far more offspring than could survive and reproduce, and individuals exhibited heritable variability. Darwin believed that under these conditions, some individuals would have a better chance of success than others. A faster cheetah would surely be more likely to catch prey than a slower cheetah, and a stronger male lion would be more likely to defend and mate with a pride of females. If this were true and these differences were inherited, then the traits of the favoured individuals would become more common in the next generation. Faster cheetahs and stronger lions would have more offspring than slower and weaker individuals of the same species. Indeed, Darwin's theory was so simple and elegant that his friend and eminent zoologist Thomas Huxley exclaimed, "How extremely stupid not to have thought of if myself!"

A contemporary of Darwin's, Herbert Spencer, used the phrase **survival of the fittest** to describe the process of natural selection. Although Darwin himself thought the expression could be a useful synonym, it can be quite misleading. You might consider an individual that lives a long life but is unable to reproduce as physically "fit," but the individual would not pass on genes to the next generation. Such an individual would not be fit with respect to Darwin's theory of natural selection, or Spencer's definition. As you will learn in Chapter 8, the key to natural selection lies in its ability to favour *reproductive* success.

survival of the fittest a phrase that has been used to describe the process of natural selection

The theory of evolution by natural selection could be extended to virtually every biological characteristic or **adaptation** (**Figure 3**). Darwin understood that with a diversity of environments, the process of natural selection acting over thousands of generations could produce an unlimited variety of species.

adaptation a characteristic or feature of a species that makes it well suited for survival or reproductive success in its environment

Figure 3 All species exhibit adaptations that make them well suited to their particular environment.

Evaluating the Theory

Darwin had proposed a revolutionary theory that challenged not only the established science of the day, but also the currently held beliefs and teachings of a large proportion of society. Darwin knew that all scientific theories must be explanatory, have predictive powers, and be testable.

EXPLANATORY POWER

As you learned in previous sections, Darwin had amassed a great deal of evidence from biogeography, the fossil record, the anatomical features of different species, and artificial breeding. Consider how Darwin might have applied his theory of natural selection to explain the evolution of large-billed finches on the Galapagos Islands (**Figure 4** and **Figure 5**, next page).

Critics of Darwin questioned the source of variability in characteristics. Although small increases in bill size seemed possible, they wondered how an ancestral giraffe with a short neck could ever evolve into a modern long-necked giraffe. Although Darwin could not have foreseen the discovery of DNA and the role that mutations play in producing variation, he did have evidence from animal breeding that suggested such dramatic changes were possible. Although the source of the variation was a mystery, Darwin argued that if dogs could be so altered in a few hundred years of artificial selection, why could nature not accomplish even greater change in thousands and even millions of years of natural selection.

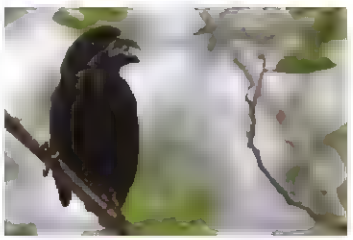
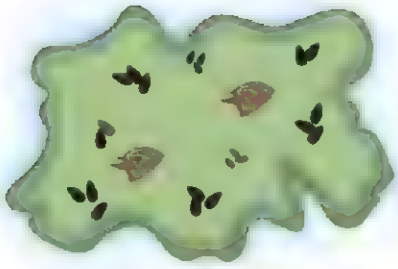
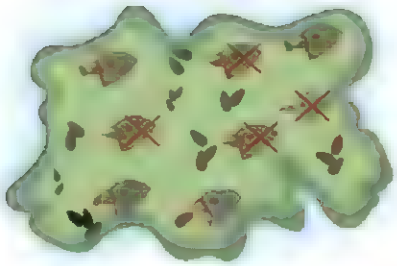


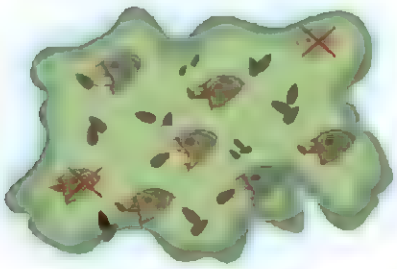
Figure 4 The large-billed ground finch of the Galapagos islands evolved from an ancestral species that possessed a much smaller bill.



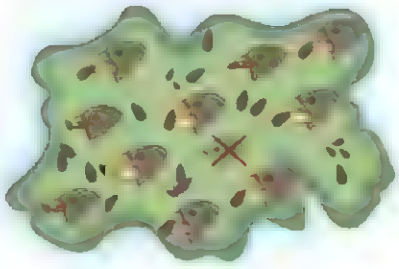
(a) An ancestral population of finches with medium-sized bills are the first seed-eating birds to arrive on the Galapagos Islands. They typically eat medium-sized seeds. With no initial competition, the finches establish a growing population on a small island with a variety of plants, some with medium seeds but most with larger seeds.



(b) The finch population grows until it reaches the limit of its food supply. Each year many eggs are laid and hatched, but the island cannot support all the birds. The birds are not all alike—like any species, they exhibit variation. Some birds have slightly larger and some slightly smaller than average bills.



(c) Most of the birds must compete for the same medium-sized seeds, but any bird with an unusually large bill is able to also feed on the larger seeds. These birds have little or no competition and ample food is available to them. Darwin would say that the environment favours, or selects, these larger-billed birds. The larger-billed birds, being healthier, lay more eggs on average. Their young are more likely to be born with larger bills.



(d) As this process is repeated generation after generation, the average bill size of the birds continues to increase. This is evolution by natural selection. Had medium-sized seeds been more common than larger seeds, the advantage of the larger bill might have been offset by the energy needed to grow the bill and/or disadvantages in reaching and manipulating the medium-sized seeds.

Figure 5 Evolution of large-billed finches on the Galapagos Islands

UNIT TASK BOOKMARK

Consider how you can use Darwin's theory of evolution by natural selection to predict outcomes related to your Unit Task topic.

PREDICTION

The theory of evolution by natural selection enables scientists to make predictions about how species may change over time. Many of these predictions are associated with changing environments. For example, the theory of evolution predicts that species will evolve in response to climate change because different environmental conditions will favour different traits. Over time, bird species may change the timing of their migration, and plants may adapt to warmer or drier conditions. Such changes are already being documented.

The theory of natural selection also predicted the evolution of antibiotic resistance in bacteria and pesticide resistance in insects. Darwin made predictions regarding the fossil record of humans. Based on the distribution of the living great apes, he predicted that fossils of the most primitive human ancestors would be found on the African continent. Darwin's predictions have been proven correct.

Investigation 7.5.1

Modelling Natural Selection (page 314)

You will design and conduct a controlled experiment to test Darwin's theory in a simulated predator–prey relationship.

TESTING AND FALSIFICATION

Darwin also knew that to be scientific, a theory must have the potential to be falsified. This means that a scientific theory must be testable—there must at least be the possibility of it being proven wrong. For example, the theory of gravity meets this scientific standard because it could be falsified by observing apples "falling up." The fact that we never find such evidence adds strength to the theory of gravity. **Table 1** (next page) illustrates a few of the kinds of evidence that could falsify the theory of evolution as well as the evidence that currently exists.

Darwin knew that if evolution had not occurred, if species had not changed over time, it should be easy to find falsifying evidence. His confidence in the theory was greatly strengthened by the complete absence of such evidence.

Table 1 The Potential for Falsification

Hypothetical observations with the potential to falsify Darwin's theory	Actual observations and evidence
amphibians and large land mammals on remote oceanic islands	No native amphibians or large land mammals have ever been discovered on remote oceanic islands.
fossils of complex organisms found in the oldest fossil deposits	Of millions of fossils, none contradict the predicted pattern of increasing complexity over time.
complex organisms with no vestigial features	All organisms that have been studied in detail exhibit many vestigial features.
species thought to be closely related that share no homologous features with each other	All organisms that have been studied in detail exhibit many features that are homologous with other closely related species.

7.5 Summary

- Darwin's theory of evolution by means of natural selection explains how the environment acts to favour the reproductive success of individuals with certain heritable traits over others.
- Darwin's theory of evolution by means of natural selection is able to explain how an adaptation can arise.
- Darwin's theory of evolution by means of natural selection can be used to make predictions about the future evolution of species.
- Darwin's theory of evolution by means of natural selection is a testable scientific theory.

7.5 Questions

1. (a) What evidence from Darwin's personal life suggests that he had developed his theory but was very hesitant to make it public?
   (b) Why do you think Darwin might not have wanted to publish his ideas? A
2. (a) How did Wallace influence Darwin's decision to publish?
   (b) Do you think Wallace should be given as much credit as Darwin for the theory of evolution by natural selection? Why or why not? K/U A
3. Use one or two examples to explain what Darwin meant by the term "selection." K/U
4. A male walrus lives to be 20 years old and mates with 18 females during its life. A second male lives to be 10 years old but mates with 44 females. Which male has natural selection "favoured?" Explain your reasoning. K/U A
5. Suggest a probable selective advantage for each of the following traits: A
   (a) clear wings of many flying insects
   (b) long tongue of a chameleon
   (c) tendrils of climbing plants
   (d) sweet-tasting and brightly coloured fruits
   (e) eel's body shape
   (f) dramatic coloration of the non-venomous false coral snake
6. When he published *On the Origin of Species*, Darwin was still planning to write a much more detailed "Big Book" on evolution. He had originally titled his book *An Abstract on the Origin of Species*. His editor convinced him to remove "An Abstract." An abstract is a short summary of a larger scientific document. T/I A
   (a) What does this suggest about Darwin's approach to science?
   (b) Darwin never completed his "Big Book." Use the Internet and other sources to learn about books that Darwin did write in the years following *On the Origin of Species*.
7. Outline the hypothetical steps that might take place as a species of bird evolves a smaller bill after reaching a remote island. K/U A
8. How did the absence of falsifying evidence increase Darwin's confidence in his theory? K/U
9. After 1858, Alfred Russell Wallace continued to correspond with Darwin and make contributions to the understanding of evolution. Use the Internet and other sources to research Wallace's thoughts on
   (a) warning coloration
   (b) the "Wallace effect" T/I

GO TO NELSON SCIENCE

7.6 The Modern Theory of Evolution

Evolutionary biology has made tremendous advances since Darwin. The science of genetics has allowed scientists to uncover the mechanism of heredity and the actual source of biological variation. The fossil record is now extensive, and our ability to interpret fossil data has been greatly enhanced by remarkable advances in the science of geology. These and other advances in science have not only confirmed Darwin's theory, but have greatly enhanced our understanding of the fundamental biology of all living things. Among these advances are our ability to accurately date the age of Earth, our discovery of the source of variation within species, and new sources of evidence in support of evolution.

The Age of Earth

Investigation 7.6.1

A Walk through Time (page 315)
Consider what you have learned about Earth's history. At the end of this chapter, you will investigate the timing of major events in the history of Earth and humans using a physical time-scale model.

Until well into the nineteenth century, many people, including some scientists, believed that Earth was less than 10 000 years old, and that the mountains, coastlines, and rivers had not changed significantly during that time. People believed that in a few thousand years, processes like erosion had not had enough time to significantly alter the physical surface of Earth. This belief was extended to living organisms. People believed that species never changed, and that species that were present then had always been present. These widely held beliefs began to change early in the twentieth century when the emerging sciences of paleontology and geology started to cast serious doubt on the belief in a young Earth.

Today there is a wide scientific consensus that Earth is extremely old. Modern geology, physics, and astronomy provide compelling evidence that Earth and our solar system are more than 4.5 billion years old, and that the universe is approximately 13 billion years old. Evidence for these values comes from many different sources, all of which are in close agreement. The evidence is largely a product of recent advances in technology and understanding.

radioisotope an atom with an unstable nucleus that is capable of undergoing radioactive decay

half-life the time required for half the quantity of a radioactive substance to undergo decay; the half-life is a constant for any given isotope

Radiometric Dating

Paleontologists are able to use radioisotopes to obtain precise estimates of the ages of rocks. **Radioisotopes** are atoms that undergo radioactive decay—a process in which the nucleus of an atom changes and releases a subatomic particle. The nuclei of these atoms are unstable and release subatomic particles changing from one form, the parent isotope, into another, the daughter isotope. For example, most carbon atoms have six protons and six neutrons and are not radioactive. However, a small fraction of carbon atoms are radioactive. They have a nucleus containing six protons and eight neutrons. When these radioactive carbon 14 (^{14}C) isotopes undergo decay, they release a high-energy particle, and one of the protons changes to a neutron. The daughter isotopes are nitrogen atoms (^{14}N), each containing seven protons and seven neutrons.

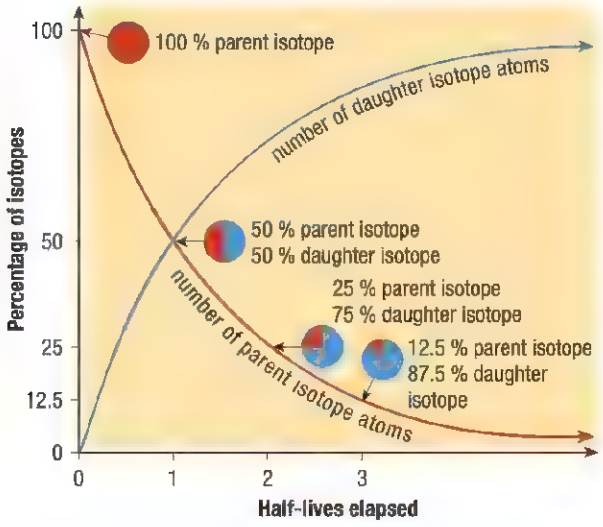


Figure 1 During each half-life of radioactive decay, 50 % of a parent isotope decays into a daughter isotope. The result is a quantitative, predictable relationship between the ratio of parent-to-daughter isotopes and elapsed time.

The complicated technique of radiometric dating is based on the ratio of parent to daughter isotopes in rock formations. Radioisotopes undergo decay in a very precise way. The length of time that it takes for half of any amount of a particular radioisotope to decay is a constant. This value, called the **half-life**, is the time it takes for exactly 50 % of a parent isotope to decay into a daughter isotope (**Figure 1**). It then takes an additional half-life for the remaining amount to be reduced by half again, and so on.

The Modern Synthesis

Darwin's theory of evolution by natural selection could account for how species evolve but could not explain the actual source of variation. Today the knowledge and understanding gained from genetics and other fields of biology have been combined with Darwin's theory to form the **modern evolutionary synthesis**. This comprehensive theory now forms the basis for all work in evolutionary biology.

modern evolutionary synthesis the modern theory of evolution that takes into account all branches of biology

Darwin defined evolution as changes in the inherited traits of a species over time. Today, biologists define evolution as changes in the gene pool of a species over time. A **gene pool** consists of all the alleles of all individuals that are currently present in a particular species or population. Individuals vary in their traits because they inherit different combinations of alleles. Natural selection acts to favour some genetic combinations over others.

gene pool the complete set of all alleles contained within a species or population

Mutations: The Source of Variation

All species exhibit genetic variation. Different individuals have different combinations of the many alleles that are already present in the population. Sexual reproduction recombines, or shuffles, these alleles and produces an almost unlimited number of combinations. New or altered traits arise when new alleles and genes are produced by mutation and acted upon by natural selection. A genetic mutation is a change in DNA. The bases that make up DNA may be switched or lost, and/or new bases may be inserted (**Figure 2**).

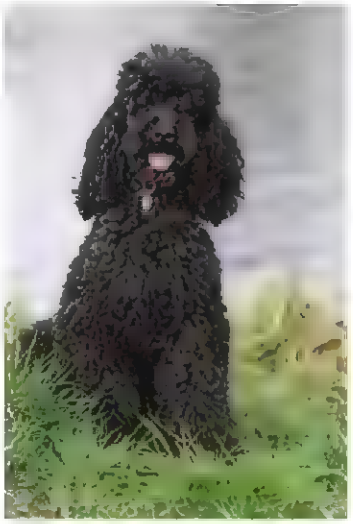


Figure 2 Perhaps hundreds of generations ago, a dog was born with a single base mutation in a gene coding for a hair protein. The mutation resulted in very curly hair—a trait that was selected for by breeders and is now common in a number of breeds, including poodles and many terriers.

Mutation events can also result in an individual having duplicate copies of genes. Duplication events are usually the result of mismatches during crossover in meiosis. A misalignment of the chromosomes during crossover causes an unequal exchange—transferring a portion of one chromosome to another (**Figure 3**). The transferred portion of the chromosome is likely to contain many genes.

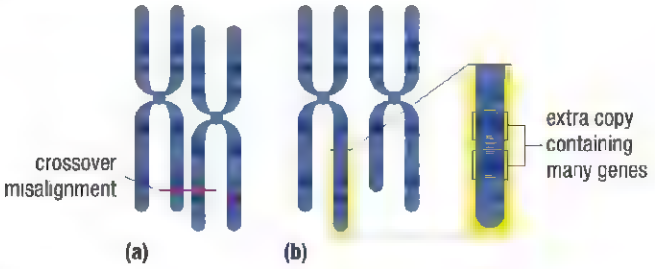


Figure 3 (a) Crossover errors can result in (b) one sister chromatid having a duplicated portion of a chromosome and the other chromatid missing a portion of the chromosome.

Gametes that receive a chromosome that is missing a section will have a low chance of survival, while gametes that receive a chromosome with duplicated genes are often viable. In fact, extra copies of genes can be beneficial. For example, scientists recently studied the gene responsible for the production of amylase, the digestive enzyme that breaks down starch. The study compared people of Japanese descent, whose traditional diet is high in starch, with Amazon rainforest dwellers, whose diet is typically low in starch. The people of Japanese descent had multiple copies of the amylase gene, enabling their cells to produce more of the digestive enzyme.

Gene duplication is an important type of mutation because it is a source of new genes. The extra copy of the gene is free to mutate and may gain a new function. Many genes code for vitally important proteins. If a mutation in a gene results in a new protein that can no longer perform a vital function, the organism may die—even if the new protein is beneficial in some other way. However, the same mutation occurring in an extra copy of the gene might result in the creation of a new and potentially beneficial protein. The duplication and mutation of gene copies can result in entire "families" of closely related genes. For example, four human genes—three involved in colour vision and one for night vision—are all thought to have been produced from a single ancestral gene.

The Effects of Mutations

As you learned in Section 7.1, mutations can be neutral, beneficial, or harmful. Most mutations are neutral because they occur in non-coding portions of DNA and therefore produce no visible change in an individual. The environment does not favour or select against individuals with neutral mutations.

Beneficial mutations, which give the individual an advantage, are selected for by the environment. For example, mutations that have allowed some plants to produce colourful flowers and attract pollinators have been beneficial to those species, and these new genes have become widespread.

Harmful mutations may make an organism less able to resist disease or avoid predators, or less efficient at obtaining food. Individuals with harmful mutations are less successful at reproducing, and therefore harmful mutations tend to disappear.

MUTATION RATES

When chromosomes, consisting of strings of DNA bases, are replicated, the error rate is typically less than one mutation in a million bases. Duplications, inversions, deletions, and other mutations are also relatively uncommon events. However, organisms have genomes consisting of millions and often billions of DNA bases. In addition, populations often consist of millions of individuals.

Individual mutation rates are very difficult to estimate, but recent studies suggest that species with large genomes are likely to have mutation rates averaging more than one per individual. The same studies suggest that humans, with genomes consisting of billions of bases, may average 20 or more mutations per individual. Even if these are almost always neutral, the numbers are staggering. The human population—approaching 7 billion people—is carrying well over 100 billion genetic mutations. A similar high incidence of mutation occurs in all species with large populations. **Table 1** summarizes key relationships between mutations and evolution.

LEARNING TIP

Consider the Numbers

Natural populations are often extremely large. A small section of forest can be home to millions of blackflies, while a soccer field is home to millions of grass plants. Even if the mutation rates for individuals are relatively low, the number of mutations within a population is very large.

Table 1 Mutation and Evolution

Factor	Influence on evolution
beneficial mutations	relatively rare but are favoured by natural selection and tend to accumulate in populations over time
harmful mutations	more common than beneficial mutations but are selected against and therefore have no influence on populations
duplication mutations	often neutral and so do not immediately benefit the individual, but provide a source of new genetic material with the potential to evolve into new genes
mutation rates	relatively low for individuals but can be numerous in populations overall

Homologous Genes and Pseudogenes

In Section 7.5 you observed that closely related species share many homologous features. All mammals, for example, have similar numbers and arrangements of bones because they have inherited this pattern from a common ancestor. Similarly, closely related species inherit homologous genes. These genes, inherited from a common ancestor, mutate and evolve over time. The degree of similarity between homologous genes provides good evidence for the degree of relatedness between species. The more closely related two species are, the more similar we would expect their homologous genes to be. **Figure 4** compares very small portions of a DNA sequence from a number of species.

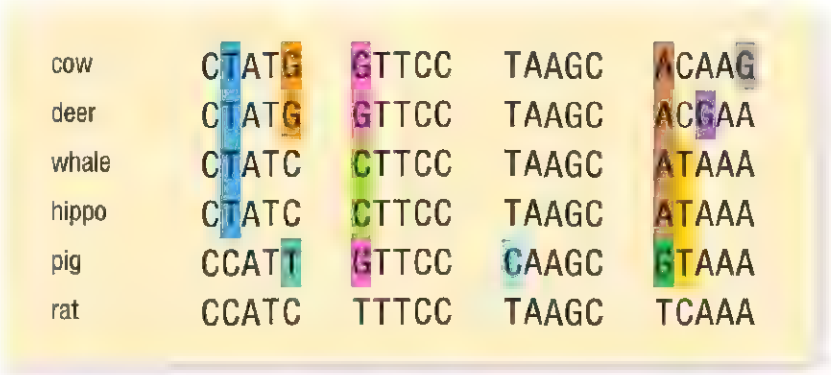


Figure 4 The letters represent the sequence of bases on the DNA of these species. All sequences code for a short portion of a homologous gene. The more closely related the species, the greater the similarity. Coloured letters highlight the differences from those of the rat sequence—the least closely related mammal. Each colour represents a different inherited mutational change.

Species also have **pseudogenes** –genes that have undergone mutations and no longer serve a useful purpose. Like vestigial anatomical features, a pseudogene is the remaining part of a gene that once served a useful purpose. For example, dolphins, like all mammals, breathe through their noses, but, unlike most mammals, have no need for a sense of smell in the air (**Figure 5(a)**). Dolphins are thought to have evolved from land mammals. Most land mammals have an excellent sense of smell. Mammals have approximately 1000 functioning olfactory receptor (*OR*) genes that code for the receptors that detect airborne chemicals. Dolphins have these same 1000 genes, but only about 200 of them are functional. The remaining 800 or so are pseudogenes. Biologists suspect that after dolphins evolved an aquatic lifestyle, their *OR* genes were of no value. Any mutations that made the genes dysfunctional would have been neutral and not selected for or against. Over millions of years most of the dolphins' *OR* genes have become pseudogenes.

Pseudogenes, like vestigial features, are found in virtually all species. For example, the stomach of the duck-billed platypus has no chemical digestive function, yet the platypus has three defective genes that code for the production of digestive enzymes normally produced by the stomach. This provides evidence that platypuses evolved from an ancestor with a stomach that released digestive enzymes coded for by properly functioning genes (**Figure 5(b)**).

The human genome contains thousands of pseudogenes. Among the most interesting is a dysfunctional copy of a GULO gene. The gene is necessary for the production of vitamin C. Humans and most other primates, bats, guinea pigs, and some birds are all known to have defective GULO genes. Mutations that cause the GULO gene to be defective are not harmful in these species because their normal diet provides adequate amounts of the vitamin.

pseudogene a vestigial gene that no longer codes for a functioning protein

Figure 5 (a) Dolphins have many pseudogenes that once coded for a keen sense of smell. (b) The platypus has pseudogenes for the production of stomach enzymes—useful in ancestors that had a functioning stomach.

Research This

Puijila, the Young Seal

Skills: Research ng, Observing, Analyzing, Evaluating, Communicat ng

SKILLS HANDBOOK A4, A5.1

Canada has been home to many remarkable fossil finds. One of the most recent is that of *Puijila darwini*—a missing link between prehistoric land mammals and modern seals (**Figure 6**). *Puijila* was discovered in Canada's High Arctic by a team led by Natalia Rybczynski, a paleontologist with the Canadian Museum of Nature in Ottawa. Dr. Rybczynski's efforts and success highlight the challenges and rewards of scientific discovery. In this activity you will have the opportunity to research th s important fossil discovery and see how paleontologists put pieces of evidence together.

Figure 6 (a) The *Puijila* fossil and (b) the Haughton crater, Devon Island, Nunavut.

1. Use the Internet and other sources to learn the details of the *Puijila* fossil discovery. Research the deta ls of Rybczynski's fieldwork, including the particular cha lenges associated with working in the Arctic.
2. Research the scientific publication of the discovery.

A. Why was this particular fossil find so important? Why was this missing link of interest? A

B. What anatomica features of *Puijila* indicate that it was semi-aquatic? T/I A

C. New fossil species are given new names. How did Rybczynski's team decide on a suitable name? A

D. Describe the formation of the Haughton crater. Why it is a good location for finding fossils? T/I A

E. Describe the events leading up to the discovery of the initial fossil and the later discovery of the skull fragment. T/I

F. In which science journal was this discovery reported? There are thousands of different journals. What makes this one special? T/I A

G. Report your findings to the class. Consider putting on a short skit to re-enact the fossil discovery. C

GO TO NELSON SCIENCE

Modern Paleontology

WEB LINK

Fossil Discovery
To learn more about how fossils are discovered, extracted and preserved,

GO TO NELSON SCIENCE

The last 100 years have witnessed many important fossil discoveries that have enhanced and enriched our understanding of evolution. These include fossils of early human ancestors and primitive whales in Pakistan. In recent decades, paleontologists have unearthed spectacular fossils of feathered dinosaurs in China and have even been able to determine the colour of some the feathers. Some new fossils of dinosaurs and other organisms have been found in Canada.

The distribution of fossils provided Darwin with important evidence for his theory of evolution. He discovered fossil remains of giant prehistoric mammals that were similar in form to present-day armadillos and sloths living in the same region. Such a pattern has now been documented in many locations around the world. Australia, for example, is home to many fossils of primitive kangaroos but has no fossils of mammals typical of other continents.

Until the 1960s, the locations of some fossils were quite puzzling. Particularly surprising was the discovery of fossils of the same species in Africa, India, and Antarctica—but nowhere else on Earth. Today the study of biogeography has been complemented by great advances in the study of **plate tectonics** and continental drift. Plate tectonics describes the movements of Earth's crust and accounts for many large surface features such as mountains, as well as volcano and earthquake activity. **Figure 7** illustrates the arrangement of some of Earth's major land masses approximately 200 million years ago. Species distributions at that time were permanently captured in the fossil record.

plate tectonics the scientific theory that describes the large-scale movements and features of Earth's crust

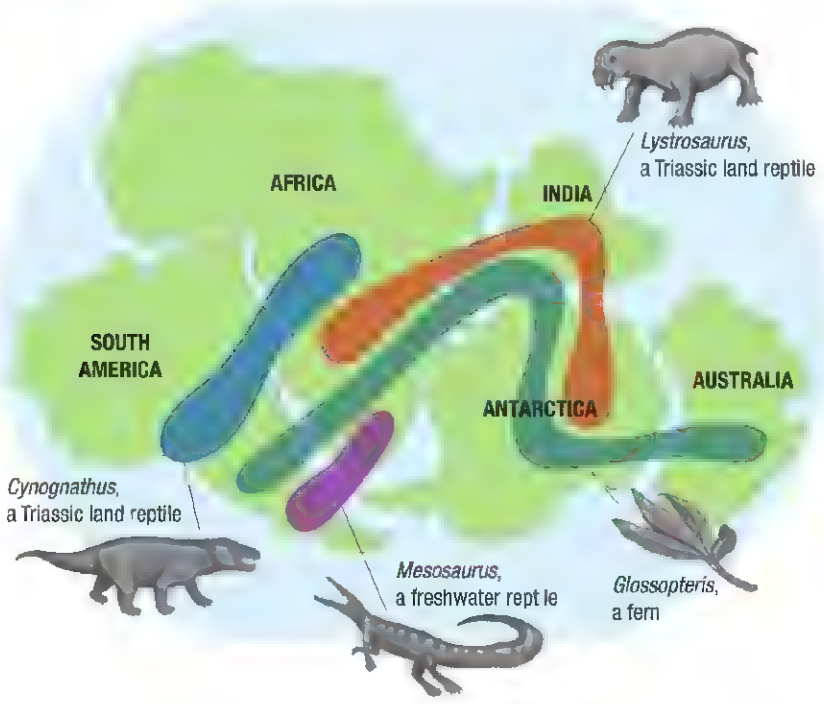


Figure 7 Fossil distributions of these four species match the arrangements of the Earth's land masses at the time the species were alive

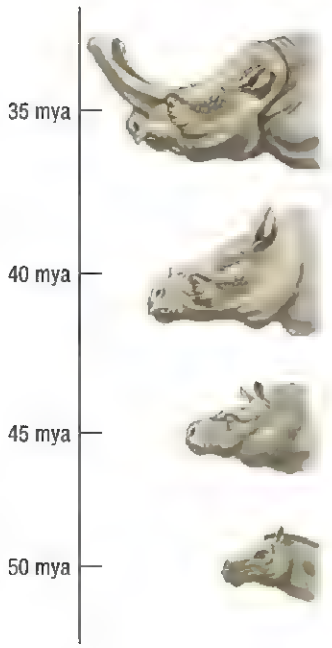


Figure 8 Evolution of an early Eocene mamma as it was thought to have appeared, based on fossil evidence (mya stands for "million years ago").

Fossils also show distinct patterns in time. The oldest fossil deposits contain only simple life forms. More recent fossil deposits contain species that are both more complex and more similar to living species (**Figure 8**). Of the millions of fossils that have been recovered and carefully documented, not a single fossil has been found to contradict this underlying pattern.

Modern evolutionary biology is supported by the most recent advances and discoveries in molecular genetics, geology, and paleontology. This has enabled scientists to understand the source of new variations within species, account for the unusual distribution of some fossils, and confirm predictions of the theory. As you will soon discover, the modern theory of evolution also has the power to explain the evolution of complex adaptations and structures, as well as explain the evolution of entirely new species.

7.6 Summary

- The modern synthesis of evolutionary biology combined Darwin's theory of evolution by natural selection with the science of genetics.
- Genetic mutations provide a continuous supply of new heritable information and variation within a species.
- Beneficial mutations are favoured by natural selection.
- Neutral mutations have no immediate influence on the success of an individual.
- Harmful mutations are selected against—reducing their frequencies within a population.
- Pseudogenes provide compelling evidence for evolution.
- The sciences of plate tectonics and paleontology have greatly enhanced our understanding of evolution.

7.6 Questions

1. How might the daily experiences of people contribute to their belief that Earth and species do not change? A
2. Approximately how old is Earth? What types of scientific evidence were used to arrive at this age? 3.0
3. Describe the relationship between the following terms: K/U A
   (a) parent isotope, daughter isotope, half-life
   (b) evolution, gene pool, species
   (c) duplication, crossing over, gene family
4. *E. coli* bacteria are extremely numerous (billions of *E. coli* cells are living inside you!) and reproduce extremely quickly. Geneticists estimate that every part of *E. coli* DNA undergoes a mutation somewhere on Earth every day. What might this suggest about the ability of *E. coli* to evolve? A
5. When geneticists examine genomes they often find "families" of very similar genes close together on the same chromosome. Explain how such families of genes might have arisen. K/U A
6. All dolphin species have hundreds of defective genes that are involved with olfactory function in other mammals. There is no evidence to believe that mutations occur any more frequently in dolphins than in other species. If this is true, why are there not as many of the same defective genes in land mammals? K/U A
7. Modern lemurs are found only on Madagascar Island off the east coast of Africa. However, fossils of ancient lemurs have been found thousands of kilometres away in India, where there are no lemurs. Consult Figure 7 on page 312 and provide a possible explanation for this finding. T/I A
8. Copy the following DNA base sequences into your notebook. They are all short samples taken from what appear to be matching chromosomes in closely related species. Compare the sequence in Species A with that of Species B, and then compare the sequence of Species A with that of Species C. T/I A

   Species A GGTAA AACAG CCTTA AGCGCC . . .

   Species B GGTAA CAACA GCCTT AAGCGC . . .

   Species C GCTAA AACAG CCCCA AGCGGC . . .

   (a) Is there any evidence that one species experienced a single base "insertion" mutation? Explain.
   (b) Which two species are probably more closely related?
9. Humans are one of a small number of mammals that are unable to synthesize vitamin C. Instead, we obtain vitamin C in our diet. Humans have a pseudogene that is homologous to a gene involved in vitamin C synthesis in other mammals. T/I A
   (a) Is the presence of this gene surprising? Why or why not?
   (b) What does it suggest about human evolution?
10. Use the Internet and other sources to research the use of carbon dating. T/I C
    (a) Why is carbon dating useful for dating samples of plant and animal material that are thousands of years old?
    (b) Explain why carbon dating cannot be used for samples that are millions of years old.

GO TO NELSON SCIENCE

CHAPTER 7 Investigations

Investigation 7.5.1 CONTROLLED EXPERIMENT

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Modelling Natural Selection

Some prey species are extremely well camouflaged. Darwin believed that the evolution of this trait was influenced by natural selection. If this is true, better-camouflaged individuals should be favoured over less well camouflaged individuals and become more common in the population over time. In this investigation, you will design and conduct a controlled experiment to test Darwin's theory in a simulated predator–prey relationship over a number of "generations."

Testable Question

Can an environment favour the success of better-camouflaged individuals in a predator–prey relationship?

Hypothesis

Formulate a hypothesis based on the testable question, after considering options for your experimental design.

Variables

As you design your experiment, carefully choose your independent and dependent variables and decide which variables will need to be controlled

Experimental Design

Your experiment must simulate a predator–prey relationship in which prey exhibit varying degrees of camouflage. There are many ways of designing and conducting such an experiment. Consider the following suggestions in your experimental design process:

- Use simple objects with different colours or patterns as your prey items (such as pieces of paper or coloured candies).
- Use different coloured or patterned backgrounds for your environment (such as paper backgrounds or natural ground covers).
- Use a student as the predator and give him or her a limited time interval in which to hunt prey.
- Use the ratio of camouflaged versus non-camouflaged individuals that survive predation to determine the ratios of the following generation. For example, if 6 camouflaged and 4 non-camouflaged individuals survive from an initial population of 20 individuals of each, then the next generation should begin with a ratio of 6:4 camouflaged to non-camouflaged individuals.
- Use the Internet and other sources to find more ideas on how to design your experiment.
- Be sure to carefully consider how you will collect and record your data. How will you design your data tables?

Equipment and Materials

- Obtain materials as required for your design.

DO NOT consume any food items used in your experiment.

Procedure

1. Research and plan your controlled experiment.
2. Obtain teacher approval for your design and gather the equipment and materials you need.
3. Conduct your experiment.
4. Record your observations in an appropriate format. Consider graphing your results.

Analyze and Evaluate

(a) Identify the major variables that you measured and/or controlled in this investigation. Which variables were manipulated (independent) and which were responding (dependent)? T/I

(b) Prepare a formal lab report on this investigation. T/I C

(c) Share your findings with other students in the class. How do your results compare with theirs? T/I C

Apply and Extend

(d) Real-world experiments of natural selection involving predator–prey relationships have been conducted on small islands in the Bahamas. Research and summarize the findings of these large-scale controlled experiments. T/I C

(e) Use the Internet and other sources to search for extremely well camouflaged species. Share your findings with the class. T/I C

(f) Try one or more online computer simulations of natural selection and/or artificial selection. Explain how natural selection differs from artificial selection. T/I

GO TO NELSON SCIENCE

Investigation 7.B.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

A Walk through Time

In this activity you will gain perspective on important events in both human history and the history of life on Earth. You will examine two timelines—one that represents major events in the history of human civilization, and one that represents major events in Earth's history. The data used in this investigation are based on historical references and the fossil record.

Purpose

To investigate the timing of major events on Earth and in human history using a physical time-scale model

Equipment and Materials

- 50 m measuring tape (one per class)
- Human Civilization Event Cards (handout)
- Life on Earth Event Cards (handout)

Procedure

1. Copy **Table 1** into your notebook. You will use it to record all observations (ya = years ago and mya = millions of years ago).

Table 1 Data Table

Human civilization events	Time (ya)	Life on Earth events	Time (mya)
Earliest human civilization		Earth forms	
Domestication of rice and wheat		First evidence of life on Earth	

2. When instructed to do so, all student groups will place their Human Civilization Event Card(s) at the appropriate positions along the same side of the tape measure, according to the values indicated on the backs of the cards. Scale: 1 m = 250 years
3. After all the cards have been placed on this scale, the entire class will "take a walk *back* through time," beginning at 0 m, which represents the present. Read and record the information from the Event Cards in Table 1.
4. Next, place your Life on Earth Event Card(s) at the appropriate positions along the opposite side of the tape measure. Scale: 1 m = 100 million years
5. After all the cards have been placed on this scale, the class will "take a walk *forward* through time," beginning at the end of the tape (50 m). Read and record the information from the Event Cards in Table 1.

Analyze and Evaluate

(a) Did the historic timing of any of the Human Civilization events surprise you? Explain. T/I

(b) Did any events demonstrate that civilization made rapid progress from 1400 to 1900? Explain. T/I

(c) Did any events suggest civilization made very slow progress between 1400 and 1900? Explain. T/I

(d) Did the historic timing of any of the major Life on Earth events surprise you? Explain. T/I A

(e) For approximately how long did prokaryotes inhabit Earth before any eukaryotes were present? T/I

(f) Approximately how long did life exist on Earth before multicellular life arose? T/I

(g) Based on these models, would you consider the following events to be ancient or recent? T/I

(i) first evidence of photosynthesis
(ii) presence of life on land
(iii) appearance of dinosaurs
(iv) extinction of dinosaurs
(v) appearance of apes
(vi) first humans

(h) Do any of the events demonstrate or suggest that major change in life on Earth is slow? Explain your thinking. T/I

(i) Do any of the events demonstrate or suggest that such change is fast? Explain your thinking. T/I

Apply and Extend

(j) In this investigation you used a linear model to represent time. Research and report on other ways of depicting the timing of events in Earth's history. T/I A C

GO TO NELSON SCIENCE

CHAPTER 7 SUMMARY

Summary Questions

1. Create a study guide based on the Key Concepts listed at the beginning of the chapter, on page 280. For each point, create three or four subpoints that provide further information, relevant examples, explanatory diagrams, or general equations.
2. Return to the Starting Points questions at the beginning of the chapter, on page 280. Answer these questions using what you have learned in this chapter. Compare your answers with those that you gave at the beginning of the chapter. How has your understanding changed? What new knowledge and skills do you have?

Vocabulary

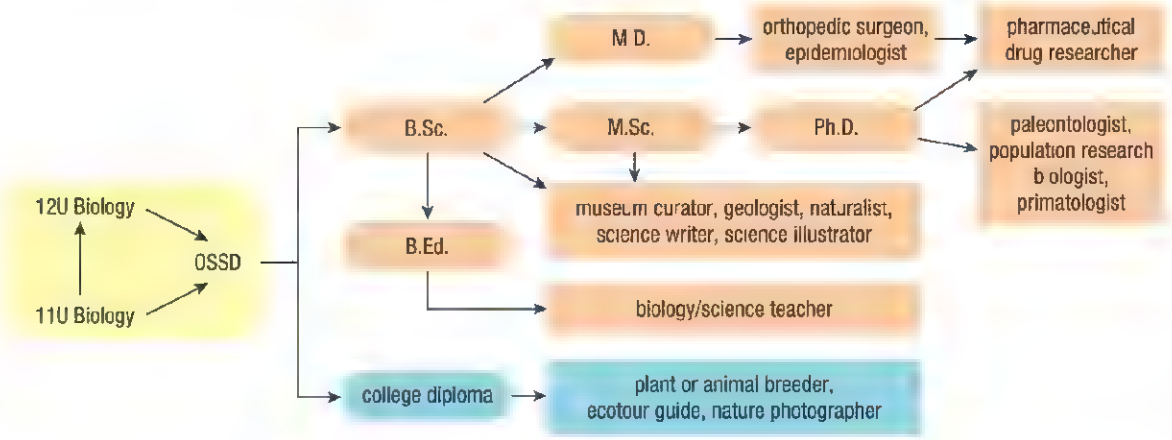
neutral mutation (p. 282)
harmful mutation (p. 282)
beneficial mutation (p. 282)
artificial selection (p. 283)
immutable (p. 288)
fossil (p. 289)
paleontology (p. 291)
catastrophism (p. 292)
uniformitarianism (p. 292)
biogeography (p. 296)
homologous feature (p. 298)
analogous feature (p. 300)
vestigial feature (p. 300)
natural selection (p. 304)
survival of the fittest (p. 305)
adaptation (p. 305)
radioisotope (p. 308)
half-life (p. 308)
modern evolutionary synthesis (p. 309)
gene pool (p. 309)
pseudogene (p. 311)
plate tectonics (p. 312)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or postgraduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select two careers related to evolution that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



GO TO NELSON SCIENCE

CHAPTER 7 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. All scientific theories are
   (a) grounded in large bodies of evidence
   (b) of great practical value
   (c) more than an educated guess or hypothesis
   (d) all of the above (7.1) K/U
2. Which of the following best describes the role of beneficial mutations? (7.1) K/U
   (a) They improve the appearance of the individuals.
   (b) They give individuals a better chance of survival.
   (c) They increase the size of individuals.
   (d) They make individuals smarter.
3. Which of the following most accurately represents the power of artificial selection? (7.1) K/U
   (a) Artificial selection reduces the number of harmful mutations that occur.
   (b) Individuals that are quite different from the original species can be produced in a controlled fashion.
   (c) Breeders typically breed two to three individuals at a time.
   (d) All mutations created by artificial breeding are either beneficial or harmful.
4. Which of the following is true regarding fossils? (7.2) K/U
   (a) All fossils are created in the ocean, when plants and organisms fall to the bottom.
   (b) Fossils have been found of most living species
   (c) Fossils are often found in unexpected locations.
   (d) Fossils show that life on Earth is very similar to the way it was 100 000 years ago.
5. Principles of uniformitarianism include which of the following? (7.2) K/U
   (a) All animals share the same DNA.
   (b) Earth is continually being changed by new forces over time.
   (c) Natural laws are dynamic and change over time.
   (d) Geological change is slow and gradual.
6. Darwin made which of the following observations in South America? (7.3) K/U
   (a) The giant fossilized armadillos and sloth specimens he found resembled the much smaller modern species.
   (b) There were many species of amphibians but no native mammals.
   (c) No birds nested on the ground.
   (d) The animals seemed most similar to those he had seen in Africa.
7. How are the populations of native species similar in Hawaii and the Galapagos? (7.4) K/U
   (a) There are no native reptiles on either island chain.
   (b) There are many unique species on both island chains.
   (c) Both island chains lie approximately the same distance away from a continent.
   (d) Both have a uniform set of habitats.
8. A pseudogene is a gene that
   (a) has undergone a mutation and no longer serves a useful purpose
   (b) is not really a gene
   (c) is harmful to the organism
   (d) used to exist in an ancestor population (7.6) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

9. For some domesticated animals, the original species is now extinct in the wild. (7.1) K/U
10. Most traditional animal and plant breeders would describe what they do as equivalent to an uncontrolled experiment. (7.1) K/U
11. All species except for a few examples (some deep-water fish, a few species of bacteria, and some ants) exhibit genetic variation. (7.1) K/U
12. According to Lamarck's principle of *use and disuse*, structures that organisms use more often become bigger and stronger. (7.2) K/U
13. Imagine that a dead fish falls to the bottom of a lake, where it is quickly covered by sediment and compressed. These are ideal conditions for a fossil to be formed. (7.2) K/U A
14. Plate tectonics is one way to explain how fossils of sea life end up on the top of high mountains. (7.6) K/U A
15. When Darwin arrived in the Galapagos on the HMS *Beagle*, he believed that Earth was dynamic and ever changing, and that species changed over time as well. (7.3) K/U
16. The 13 species of Darwin's finches in the Galapagos fill the same ecological niches. (7.3) K/U
17. The number of bones in an animal's skeleton can be used to identify relationships between species. (7.4) K/U
18. Until the nineteenth century, many people believed Earth was less than 6000 years old and its physical features had changed significantly over that time. (7.6) K/U

To do an online self-quiz,
GO TO NELSON SCIENCE

CHAPTER 7 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. A scientific theory is
   (a) an educated guess
   (b) an explanatory model that is backed by a very large body of data
   (c) one of many possible explanations about a phenomenon
   (d) complete and perfectly accurate (7.1) K/U
2. Most mutations are
   (a) neutral
   (b) harmful
   (c) beneficial
   (d) mixed (harmful to some and beneficial to others) (7.1) K/U
3. Which human activity is a response to an evolutionary change? (7.1) K/U
   (a) the domestication of animals
   (b) the development of annual flu shots
   (c) artificial selection
   (d) cloning
4. Which species have been shown to change through mutation over relatively short periods of time? (7.1) K/U
   (a) mammals
   (b) bacteria
   (c) birds
   (d) moulds and mushrooms
5. Why are bacteria that exhibit resistance to antibiotics becoming more widespread? (7.1) K/U
   (a) Antibiotics kill viruses, not bacteria.
   (b) Less-resistant strains of bacteria replicate more slowly than more-resistant strains.
   (c) More resistant strains of bacteria have longer lifespans than less-resistant strains.
   (d) Less-resistant strains of bacteria are being killed off by antibiotics.
6. In the 1700s, which of the following scientists claimed that life may have evolved from a single source? (7.2) K/U
   (a) Georges-Louis Leclerc de Buffon
   (b) Carl Linnaeus
   (c) Erasmus Darwin
   (d) Chevalier de Lamarck
7. African bush babies hunt at night. They have very large eyes. For Chevalier de Lamarck, the excellent night vision of bush babies would support which of his principles of evolutionary change? (7.2) K/U
   (a) effect of exercise
   (b) predator advantage
   (c) use and disuse
   (d) inheritance of acquired characteristics
8. Most fossils form
   (a) underwater
   (b) in amber
   (c) in caves
   (d) in permafrost (7.2) K/U
9. In Patagonia, while on a five-year voyage of discovery, Charles Darwin found fossils of extinct armadillos and sloths. What observations did he make about armadillos and sloths that would later support his theory of evolution? (7.3) K/U
   (a) The extinct animals were larger than modern species of these animals in Africa.
   (b) Modern and extinct animals that resembled each other seemed to share similar geographical distributions.
   (c) There are no modern-day armadillos and sloths in South America.
   (d) The fossils of the extinct armadillos and sloths were mixed in with marine fossils.
10. In 1838, the Reverend Thomas Malthus claimed that the size of animal populations is limited by the
    (a) availability of shelter
    (b) availability of oxygen
    (c) age at which the animals became sexually mature
    (d) availability of food (7.4) K/U
11. Which of the following statements is incorrect? (7.2, 7.4, 7.5) K/U
    (a) Lamarck proposed that individuals could pass on traits that they acquired during their lifetime to their offspring.
    (b) Lyell revolutionized geology by suggesting that geological change is slow and gradual.
    (c) Cuvier's studies on fossils revealed that complex fossils are found only in the oldest rocks.
    (d) Darwin's theory of natural selection explains that the environment favours some individuals over others.

12. Gene duplication
    (a) provides a source of new genes
    (b) is usually a harmful mutation
    (c) produces pseudogenes
    (d) none the above (7.6) K/U

Match the term on the left with the most appropriate description on the right.

13.

(a)	homologous features	(i)	features that no longer serve the function they do in similar species
(b)	vestigial features	(ii)	features that serve the same function in different organisms but are different in structure
(c)	analogous features	(iii)	similar structures of organisms that have different functions
(d)	anatomical oddity	(iv)	features that serve an unusual purpose or have a structure that is difficult to explain (7.4) K/U

14.

(a)	genome	(i)	all the alleles currently present in a particular species or population
(b)	gene pool	(ii)	genes inherited from a common ancestor
(c)	homologous genes	(iii)	genes mutated to the point at which they no longer serve a useful purpose
(d)	pseudogenes	(iv)	the full set of genes that an organism inherits from its parents (7.6) K/U

15. Match Darwin's inferences, on the left, with his observations, on the right.

(a)	Some individuals will inherit characteristics that are of benefit and increase their chance of reproductive success.	(i)	Populations produce more offspring than can survive to adulthood.
(b)	Individuals of all species compete for resources.	(ii)	Individuals of all species show variability.
		(iii)	Resources for any species are limited.
		(iv)	Populations do not continue to grow forever.
		(v)	Some variability is heritable. (7.5) K/U

Write a short answer to answer each question.

16. Describe the physical characteristics of the Galapagos Islands. How were they formed? What is the predominant environment on these islands? (7.3) K/U
17. What unusual behaviours of animals have been observed on remote islands? What is a possible explanation for these unusual behaviours? (7.4) K/U
18. New scientific theories, particularly those that challenge current beliefs, will be closely examined before they become widely accepted. All scientific theories should meet what three criteria? (7.5) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

19. The work of animal and plant breeders is similar to running uncontrolled experiments. (7.2) K
20. Lamarck believed that adult giraffes that stretched their necks to reach food would produce offspring with slightly longer necks. This is an example of his principle of *use and disuse*. (7.2) K
21. The youngest sedimentary rocks contain fossils of less complex organisms than the fossils found in older deposits. (7.2) K
22. Scientists who study fossil organisms to learn about prehistoric life are called paleontologists. (7.2) K
23. Darwin observed that there were many native species of amphibians in the entire Galapagos Islands. (7.3) K
24. After his visit to the Galapagos, Darwin concluded that all the species that lived there must have arrived by air or water. (7.3) K
25. On many remote islands, such as Hawaii, species introduced by humans are struggling. (7.4) K
26. Charles Darwin concluded that closely related species had homologous features because they live in the same habitat. (7.4) K
27. Radioisotopes are molecules that undergo radioactive creation. (7.6) K/U

Understanding

Write a short answer to each question.

28. What is artificial selection, and why is it called "artificial"? (7.1) K
29. Describe the results of the 100 year corn seed experiment and explain their significance. (7.1) K
30. Scientists in the 1700s who believed in the immutability or perfection of animal species were puzzled by anatomical features that seemed to serve no purpose. Why were they puzzled? Provide one example of such a feature. (7.2) K

31. What is amber, and how are fossils of insects created in amber? (7.2) K

32. Why is it rare to find fossils that include soft body parts, such as organs? (7.2) K/U T/I

33. Scientists have long been interested in fossils as a way to learn about prehistoric life on Earth. Which of the following statements are true? If you think a statement is false, rewrite it to make it true. (7.2) K/U
    (a) There are many fossils of living species.
    (b) Fossils are often found in unexpected locations, such as fossilized fish on the top of mountains.
    (c) Dinosaur footprints are not considered fossils.
    (d) Fossils have been found very deep in the Earth, sometimes at a depth of more than 1 km.

34. When Darwin reached the Galapagos, he gathered thousands of specimens and filled notebooks with detailed observations. (7.3) K/U
    (a) Species he observed there bore a striking resemblance to species on what continent?
    (b) Did Darwin think his finch specimens represented varieties of a single species or of different species?
    (c) Did Darwin find any native species of large land mammals?
    (d) Did Darwin find any native species of amphibians?

35. An examination of Hawaiian native species supports Darwin's hypothesis. Identify which of the following statements are true. If you think a statement is false, rewrite it to make it true. (7.4) K/U
    (a) There are many species of unique plants, birds, and insects in Hawaii.
    (b) In contrast to the Galapagos, there are no native terrestrial reptiles. This observation makes sense because Hawaii is much more remote.
    (c) Bats, rats, and lemurs are the only native mammals.
    (d) Over 270 native Hawaiian species have gone extinct since the arrival of Europeans in 1778.

36. Assume a classmate of yours says, "I don't think the pattern of native species on islands proves anything about how they were introduced. I bet goats or cats, for example, simply cannot survive on these islands." How would you counter that argument? (7.3) K/U

37. You have probably experienced goosebumps when you were cold or scared. (7.4) K/U
    (a) How might goosebumps have helped humans in the past?
    (b) Do goosebumps serve a purpose for humans now?

38. Alfred Russell Wallace and Charles Darwin proposed virtually identical theories of how species evolved. Describe differences in their approach to publication, their ages, and the geographical areas where they worked. (7.5) K/U

39. Copy and complete **Table 1**. The left column displays ideas from different theories. Identify the theory with which each idea is associated by putting a single X in each row. (7.2, 7.5) K/U

Table 1 Theories of Evolution

	Catastrophism	Uniformitarianism	Natural selection
Earth has changed by the same processes in the past as in the present.			
Species, themselves, do not change over time.			
Over thousands of generations, an unlimited variety of species may be created.			
Floods and other events cause extinctions. These species are replaced by a new set of species.			
"Fitness" refers to an organism's ability to achieve reproductive success.			
Natural laws are constant and eternal.			

40. Consider the organisms shown in Figure 3 on page 305. Describe the adaptations exhibited by each organism (7.5) K/U A

41. What evidence has been uncovered that platypuses descended from an ancestor that relied on digestive enzymes to break down food in its stomach? (7.5) K/U

42. How might the bill of this Galapagos finch provide selective advantage (**Figure 1**)? (7.5) K/U

Figure 1 Galapagos large-billed ground finch

43. Explain how the half-lives of radioisotopes can be used to date rocks. (7.6) K/U

Analysis and Application

44. Plant breeders have bred many plants to make it easier to transport them from one location to another. That is one reason you now see fruits and vegetables from around the world in your grocery store. What sorts of traits do you think the plant breeders look for to allow transportation of food across great distances? (7.1) K/U C A

45. The sickle-cell mutation gives carriers resistance to malaria. However, this mutation can also result in sickle-cell anemia—a serious enough condition that some sports organizations have recently approved mandatory testing for sickle-cell carrier status of student athletes. Explain what you can learn from this example about gene mutations. (7.1) T/I A

46. Why might artificial selection make a species more vulnerable to disease? (7.1) A T/I

47. The World Health Organization and other health agencies develop a new flu vaccine every year. Why is this necessary? (7.1) T/I A

48. Mutations that provide a selective advantage tend to become more prevalent in populations over time. Explain how this occurs. (7.1) T/I A

49. What could you learn by studying paths of fossilized footprints of an animal? (7.2) K/U A

50. Some fossils are buried very deep in the Earth. What are some of the ways in which you think these fossils are found? (7.2) T/I A

51. There is some truth in the theory of catastrophism, even though Cuvier's conclusions have been disproven. Explain. (7.2) T/I A

52. Biologists now have many more tools or methods to study the relationships between species than they had in Darwin's day. List the tools or methods Darwin might have used as well as some new methods in use today. (7.2) T/I A

53. What can fossilized fecal remains tell us about the past? (7.2) K/U

54. Flightless cormorants (*Phalacrocorax harrisi*) are the only cormorants that do not fly. They live only in the Galapagos Islands. (7.3) K/U T/I A
    (a) Why did these cormorants lose the ability to fly?
    (b) How do the flightless cormorants illustrate Charles Darwin's theory of evolution?

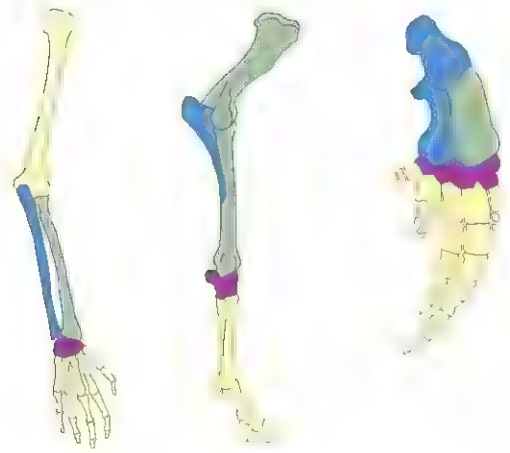
55. The frigate bird has webbed feet but never enters the water. (7.4) T/I A
    (a) What type of feature is this?
    (b) Suggest an evolutionary explanation to account for this feature.
    (c) Speculate on how the frigate bird's feet may evolve over time. Explain your reasoning.

56. Some animals produce only a few young at a time, while others produce hundreds, if not thousands, of eggs at a time. What do you see as the advantages of each approach? (7.4) K/U T/I

57. **Figure 2** shows embryos of a chicken and a human. Describe two homologous features that these embryos share. (7.4) K/U

Figure 2 Embryos of (a) a chicken and (b) a human

58. **Figure 3** shows the forelimbs of different organisms. (7.4) T/I A
    (a) Are these homologous or analogous features?
    (b) Explain your answer.



(a) human (b) horse (c) whale

Figure 3

59. What is the study of biogeography? How would studying biogeography provide further evidence to test Darwin's theory of evolution? (7.4) T/I
60. After millions of years of isolation, native bird species in New Zealand evolved into a wide array of unique species. Bats were the only native terrestrial mammals, so birds were able to move into ecological niches filled by mammals on other continents. Provide three possible reasons why many of these bird species were driven to extinction or near-extinction when humans arrived on the island around 1200 years ago. (7.4) T/I A
61. What evidence suggests that whales have descended from a land mammal? Do you find this evidence convincing? Why or why not? (7.4) T/I A
62. What are dew claws and how does evolution account for them? (7.4) T/I
63. In early developmental stages, the embryos of all vertebrates, including humans, chickens, and fish, possess a short, bony tail. Human embryos also have gill slits. Use the theory of evolution to account for these observations. (7.4) T/I
64. Darwin's theory of evolution can help scientists predict ways in which species will need to change in response to climate change. Why? (7.5) T/I A
65. Some animals have evolved protective coloration. Examine the moth in **Figure 4**. (7.5) T/I A
    (a) Is this an example of camouflage?
    (b) What do you think this pattern represents?
    (c) Why does natural selection favour the evolution of this pattern?

Figure 4

66. Rock pocket mice live in Arizona desert and occur in two colours (**Figure 5**). Their desert surroundings include regions of dark lava rock and of light rubble. (7.5) T/I A
    (a) Prior to taking these photos, the two mice were "switched." How might this change affect their survival?
    (b) Do you think the colours of pocket mice will continue to evolve? Explain.

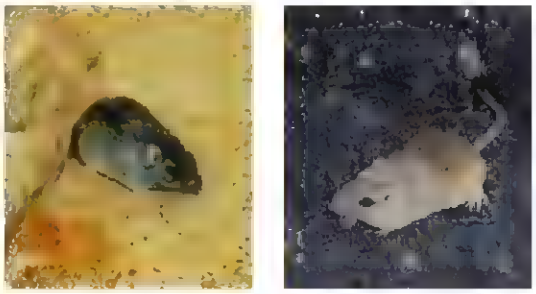


Figure 5

67. Plate tectonics can be used to explain why organisms on different continents share homologous features. Explain and provide examples. (7.6) K/U A
68. Why does a high incidence of mutation occur in all species with large populations? (7.6) T/I A
69. How can gene duplication be considered a long-term beneficial form of mutation that can lead to selective advantage? (7.6) T/I A

70. Crossing over mutations can result in gametes that are missing a section as well as gametes that have duplicated genes. Which of these types of gamete is generally more likely to be successful? Why? (7.6) T/I A

Evaluation

71. Suppose you are a paleontologist. (7.6) T/I A
    (a) In what part of the world would you focus your energies when looking for fossils?
    (b) What type of organisms would you search for?
    (c) What could you learn from other scientific disciplines to help you in your work?
72. Suppose you are a paleontologist and you find a fossil that appears to be unlike any other fossil ever found. What are some of the things you might do to figure out what it is and where it fits in its ancestral tree? (7.6) T/I A

Reflect on Your Learning

73. In what circumstances do you think cloning technologies should be used? For example, it is okay to genetically modify our food? To clone human embryos for research? To clone human beings? Back up your opinions with facts. T/I A
74. Mutation rates for any individual, such as you or the family dog, are relatively low. However, even with low mutation rates for individuals, the number of mutations for the population as a whole can be huge. Why is this? And what is the implication of this difference for evolution of the gene pool? T/I A
75. Lamarck's principles of evolution were correct in some ways and flawed in others. To what extent do you think he was correct? And how was his reasoning flawed? K/U T/I A
76. When Darwin went on his voyage of discovery, he believed in the immutability of species. His observations, both during and after his voyage, caused him to change his views. How hard do you think it would have been for Darwin to move away from beliefs that were prevalent during his day? How do you think he was able to do that? T/I A
77. Island biogeography is a field of study that originally focused on actual islands. Now it is used to study other areas, such as parks surrounded by human habitation and mountains surrounded by deserts. Explain why this makes sense. T/I A
78. Do you think domestication is good or bad for animals? A
79. Comment on the overall influence of domesticated species on humans and on the environment. Do you think that species domestication was a good idea? T/I A
80. "Survival of the fittest" describes the importance of a particular type of fitness in the evolution of the species. Identify that type of fitness and explain why it is important for evolution. What other types of fitness are important, in your view, for animals? For people? T/I A
81. You have learned about a variety of research disciplines in this chapter. Which one is the most appealing to you? Explain your choice. A
82. What determines whether or not a mutation is beneficial? A

Research

GO TO NELSON SCIENCE

83. Why would an acidic bog be a good place to preserve bodies? Research the Tollund Man and write a short report about this mummy, including the mummy's age, where it was found, the cause of death, the presence or absence of soft tissues, and scientists' discoveries regarding the dead man's last meal. T/I C A
84. What is the origin and fate of pseudogenes? Write a short report about your findings. T/I C A
85. Research the pros and cons of selective breeding on agricultural crops developed with the goal of helping populations in less developed countries. T/I C A
86. Besides his studies in the South Pacific, Darwin drew on his observations of dogs to form his theory of evolution. Research the evolution of dogs. For example, how many breeds now exist? What is the role of artificial selection in the evolution of the dog? T/I C A
87. Identify and write a short report about an interesting vestigial feature or anatomical oddity that is not mentioned in this textbook. What do you find interesting about it? T/I C A
88. Select a domesticated plant, and research the history of its domestication. Identify the traits that have been selected for, along with the value that the domesticated species provides to humans today. To what extent has the species been altered by this process of artificial selection? T/I C A
89. Research the effect that urbanization has had on the bamboo forests of China. What impact has this had on the reproductive success of the giant panda? What measures have been taken to reduce this impact? T/I C A

CHAPTER 8

The Origin of Species

KEY CONCEPTS

After completing this chapter you will be able to

- describe the various forms of natural selection and other factors that can result in evolutionary change
- describe the process of speciation
- describe and explain major patterns of evolutionary change
- apply the theory of evolution and use it to make testable predictions
- outline major steps in human evolution
- explain how human actions influence the evolution of species and extinction rates

What Steps Lead to the Evolution of New Species?

Darwin's theory of evolution by natural selection and the evidence that supports it have convinced biologists that Earth's biodiversity—the millions of species alive today, as well as the countless millions that have lived in the past and are now extinct—are all products of evolutionary change.

Given our understanding of DNA, inheritance, and mutation, it is not difficult to accept that the genetic makeup of a species might change over time. In addition, given the human experience in plant and animal domestication, it is also quite obvious that selection can lead to significant changes in species over time. But how can selection and mutation result in major evolutionary changes, including the evolution of millions of different species? And why, if the theory of evolution is true, are there still so many "primitive" species? Why have all species not evolved into more advanced organisms? As you will learn, the answers hinge on the word "different."

Each of the millions of different species that are living and have lived on Earth is unique. Each species has specialized features that make it well suited to a particular ecological niche in a particular place and time. The mudskipper in the photograph on the next page is a wonderful living example of a specialized species. Mudskippers are amphibious fish, spending part of their time under water and part on land. When tides are low, mudskippers move around on the exposed beach, capturing small prey and defending their territory. During high tide or when they are threatened, they hide in burrows that they dig in the soft substrate. Mudskippers have many adaptations that support this lifestyle. Like many frogs, they can breathe through their damp skin and the roofs of their mouths. When on land, they also trap large bubbles of air inside their gill pouches to provide more oxygen to the gills than would be available in a small pocket of water. It would be a mistake to think that these fish are "on their way" to becoming fully terrestrial vertebrates. Instead, we should recognize that they are filling an ecological niche that favours their success.

In this chapter you will learn how different factors and circumstances have led to both the evolution of species, including our own, and to mass extinction events. You will also learn how understanding the evolutionary history of a species can be of benefit today.

STARTING POINTS

Answer the following questions using your current knowledge. You will have a chance to revisit these questions later, applying concepts and skills from the chapter.

1. What human characteristics or adaptations do you think are most responsible for our success as a species?
2. What human features do you consider least advantageous? In what ways are some human features disadvantageous under certain conditions?
3. Brainstorm possible situations that you think might cause one species to evolve into two different species.
4. Extinction is a natural process. Do you think there is any reason to be worried about species becoming extinct today? Explain your reasoning.
5. Do you think it is possible for human actions to influence how other non-domesticated species evolve? If so, how?

Mini Investigation

Simplicity, Complexity, and Diversity

Skills: Performing, Analyzing

SKILLS HANDBOOK A2.1

The word "primitive" is often used incorrectly from a biological perspective. You might hear someone describe a snail as being "more primitive" than a mammal. In biology, however, the word "primitive" means ancient. Primitive species are those that lived millions of years ago. In contrast, all organisms that are alive today are "modern" species. The biological distinction is that some lineages have remained simple, while others have evolved to be highly complex. You might wonder why some species have remained simple while others have become complex. You might also wonder why species are so different. If natural selection favours beneficial traits, why do all species not have the same traits? In this activity, you will consider answers to these questions and gain insights into the factors that are responsible for the formation of new species.

Equipment and Materials: Selection Scenario Cards

1. Obtain a Selection Scenario Card from your teacher or by visiting the Nelson website. Each card describes a particular scenario and one characteristic that would likely be strongly influenced by natural selection in that scenario. The card also lists two species.
2. With your partner or group, brainstorm the natural selection pressures that might influence the chosen characteristic in this particular scenario. Create a list of your ideas.
3. Consider the particular characteristics of the two species. Which species do you think would be more successful in this particular scenario? Record your decision and include a brief explanation of your reasoning.
4. Exchange Selection Scenario Cards with another group and repeat the exercise.

A. Were complex species always best suited to take advantage of a particular set of environmental conditions? Use examples to support your answer. T/I

B. Compare your results with others' results. Did all student groups reach the same conclusions? T/I

C. What do your conclusions suggest about the relationship between species and their success under different environmental conditions? T/I A

GO TO NELSON SCIENCE

8.1 Natural Selection

Evolution occurs when natural selection acts on the genetic variability within populations. Genetic variation arises by chance through genetic mutations and recombination. The process of natural selection, however, does *not* occur by chance. The environment favours certain individuals over others. Just as human breeders have artificially selected for specific characteristics in domesticated plants and animals, the environment selects individuals that are better suited to their environment.

Sickle-cell anemia is a useful example of how mutation, genetic variation, and natural selection can lead to a change in a population. In humans, the sickle-cell allele resulted from a single base mutation in the DNA coding for hemoglobin. Individuals who are heterozygous for the allele are resistant to malaria and thus have a better chance of surviving than those who lack the allele. **Figure 1(a)** shows the distribution of malaria in Africa. People living in this region who are born with the sickle-cell allele are more likely to survive than those born without the allele. With survival comes reproduction and the passing on of the sickle-cell allele to the next generation. Over time, the result has been an increase in the frequency of the allele within those populations (**Figure 1(b)**). The sickle cell mutation may never have occurred in the populations living in the malarial regions of northern Africa and the island of Madagascar.

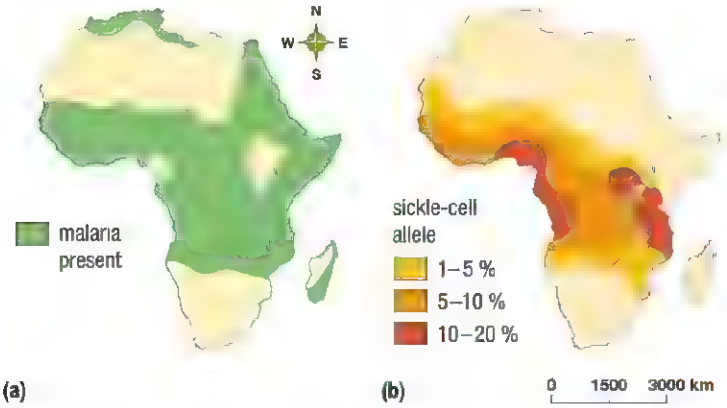


Figure 1 In the parts of Africa (a) where there is a high level of malaria, (b) the sickle-cell anemia allele is more prevalent.

Types of Selection

Selective pressures may result from any number of abiotic or biotic factors: diseases, climatic conditions, food availability, or predators—even your choice of mate! These selective pressures can result in different patterns of natural selection.

Directional Selection

directional selection selection that favours an increase or decrease in the value of a trait from the current population average

Directional selection occurs when selection favours individuals with a more extreme variation of a trait. The result is a shift away from the average condition. Directional selection is very common in artificial breeding, where individuals with an enhanced trait are often selected. Strawberries have been selected for larger and sweeter fruits, chili peppers for hotter flavour, and thoroughbred horses for running speed.

Figure 2 There are more than 300 species of hummingbirds. Their bill lengths can vary dramatically from species to species.

Consider the following example of directional selection in nature. Hummingbirds use their bills to feed on nectar (**Figure 2**). Suppose a population of hummingbirds enters a new habitat with plants that have longer flowers. The hummingbird population includes individuals with a variety of bill lengths, though most have a bill best suited to medium length flowers (**Figure 3(a)**, *before selection*, next page). In the new habitat, individuals with slightly longer bills are favoured by the environment and will be more successful than those with medium-length and shorter bills. Longer-billed birds will obtain more food and contribute more offspring to later generations (**Figure 3(a)**, *after selection*, next page). Eventually the bill length of the population will increase.

Stabilizing Selection

Stabilizing selection occurs when the average phenotype within a population is favoured by the environment. For example, imagine an initial population of hummingbirds that lives in an unchanging environment with medium-sized flowers (**Figure 3(b)**, *before selection*). The most common medium-billed hummingbirds will be favoured. A longer bill requires more nutrients and energy to grow and carry around, while a shorter bill may reduce a bird's ability to reach food within the flowers. Selective pressures will reduce the reproductive success of individuals that exhibit extremely long or short bills (**Figure 3(b)**, *after selection*).

stabilizing selection selection against individuals exhibiting traits that deviate from the current population average

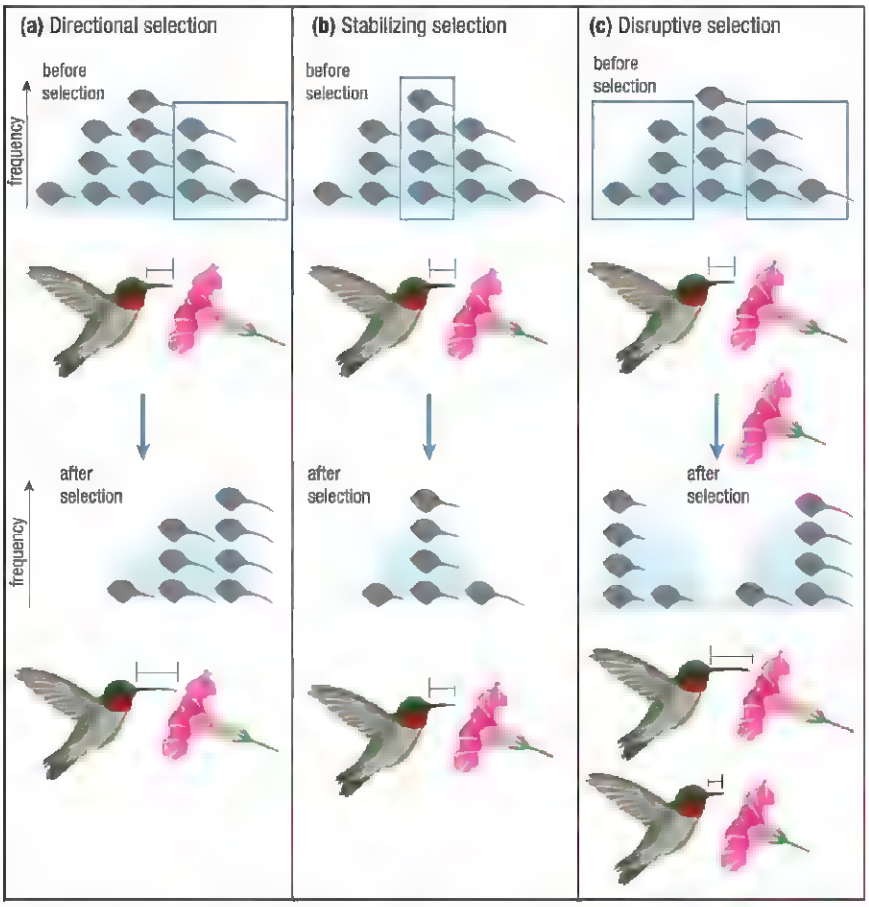


Figure 3 Examples of selection in a population of hummingbirds. (a) In a new environment with longer flowers, directional selection will favour individuals with longer bills. (b) In stabilizing selection, individuals with an average bill length are favoured. (c) In disruptive selection, the environment favours individuals with long and short bills over individuals with average bill lengths.

Human birth weights are also subject to stabilizing selection. Birth weights are variable, and part of this variability is heritable. According to the theory of evolution by natural selection, babies born at weights offering the best chance of surviving birth should be more numerous. More human babies are born weighing just over 3 kg than with any other weight. Babies with significantly lower weights are often developmentally premature and less likely to survive, while heavier babies often experience birth-related complications that threaten the life of both baby and mother (**Figure 4**).

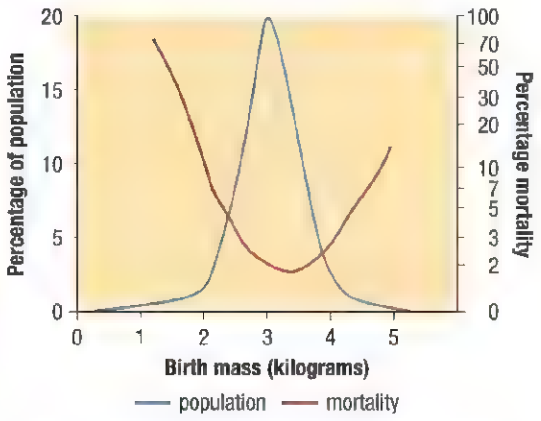


Figure 4 Human babies with average birth weights have a higher rate of survival than very large or very small babies.

Disruptive Selection

disruptive selection selection that favours two or more variations of a trait that differ from the current population average

Disruptive selection favours individuals with variations at opposite extremes of a trait over individuals with intermediate variations. Sometimes, environmental conditions favour more than one phenotype. For example, two species of plants with different-sized flowers may be available as a food source for the hummingbird population (**Figure 3(c)**, *before selection*). Each species is a good source of nectar, but neither is well suited to a hummingbird with a medium-length bill. Birds with longer and shorter bills will be more successful and will contribute more offspring to later generations (**Figure 3(c)**, *after selection*).

Sexual Selection

sexual selection differential reproductive success caused by variation in the ability to obtain mates; results in sexual dimorphism, and mating and courtship behaviours

Natural selection favours the reproductive success of individuals with certain traits over individuals with other traits. Good health enhances reproductive success, but finding a mate is even more important. **Sexual selection** is the favouring of any trait that specifically enhances the mating success of an individual. Sexual selection often leads to the males and females of a species evolving appearances and behaviours that are quite different from each other.

The most common forms of sexual selection are female mate choice and male-versus-male competition. In many species, females choose mates based on physical traits, such as bright coloration or behaviours (**Figure 5(a)**). In other species, males have evolved larger body size and other physical attributes such as antlers that are often used in direct competition (**Figure 5(b)**). The males often fight each other to establish control over a territory that is home to females with which they can mate. The difference between success and failure can be dramatic. For example, a very successful male elephant seal may mate with dozens of females each year and hundreds of females in his lifetime, while a weak male may live a longer life but produce no offspring. In this case the genes of the shorter-lived but dominant male are destined to become more common in succeeding generations.

Investigation 8.1.1

Bird Monogamy and Sexual Dimorphism (page 366)
In this observational study you will make a prediction based on the theory of evolution and gather data to test your prediction.

Figure 5 (a) Male cardinals use brightly coloured plumage and song to attract females. (b) Male bighorn sheep compete head to head, using their horns for head-on clashes. Female bighorn sheep have much smaller horns.

UNIT TASK BOOKMARK

Consider how you can use the different types of selection to predict outcomes related to your Unit Task.

While traits such as bright coloration and large antlers can be favoured by sexual selection, they are often a disadvantage when it comes to longevity. Avoiding predators is not made easier by brilliant plumage or a distinctive song. Fringe lipped bats, for example, locate male tungara frogs by listening for their mating calls. Male frogs that call frequently are more likely to be eaten. Male frogs that never call remain safe but are unable to attract a mate.

Sexual selection is not limited to animal populations. Colourful flowers and scents are the most obvious sexual features of plants (**Figure 6**). Rather than attracting mates, these features attract pollinators. By maximizing their chances of being pollinated, plants have a greater likelihood of contributing more alleles to the next generation's gene pool.

Figure 6 Attracting more pollinators may ensure greater seed production.

Natural Selection in Action

Natural selection results in evolutionary changes within populations. Examples of such changes can be observed in nature and demonstrated under controlled experimental conditions.

Geneticists have recently revealed an example of directional selection in a human population. Tibetan people have inhabited the Himalayan mountains for thousands of years (**Figure 7**). At this elevation, the oxygen level is only 40 % of that at sea level. When people from lowlands move to this elevation, their bodies exhibit a physiological response. Over a period of days and weeks, their red blood cell count increases, helping them obtain adequate oxygen. This survival response, however, is not ideal because the increased red blood cell count makes blood more viscous. This places stress on the heart and results in reduced fertility and increased child mortality. Tibetans who live at high altitudes, however, do not exhibit elevated red blood cell counts yet have no difficulty coping with the low oxygen levels. Instead, directional selection has favoured a number of genetic mutations that increase the oxygen-carrying capacity of their blood while maintaining normal red blood cell counts. Geneticists have documented more than 30 genes that have been selected within the Tibetan population. One allele was almost 10 times more common in Tibetans in the study group than among people of lowland descent.

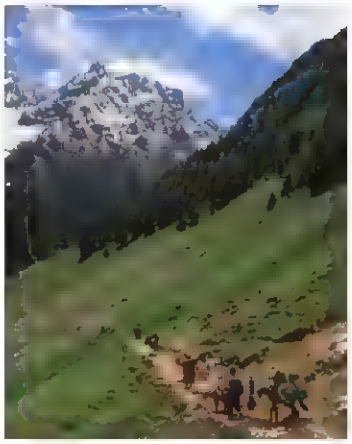


Figure 7 Tibetans living at high elevation have blood with a high capacity to carry oxygen.

Under controlled experimental conditions, researchers at the University of Wisconsin tested the hypothesis that certain behaviours might have an inherited component and could be influenced by natural selection. The researchers modelled directional selection in populations of mice by choosing individuals for breeding that spent the most time on exercise wheels. After only 10 generations, the populations descended from the chosen mice exhibited much higher running distances and average speeds when compared to control populations (**Figure 8**).

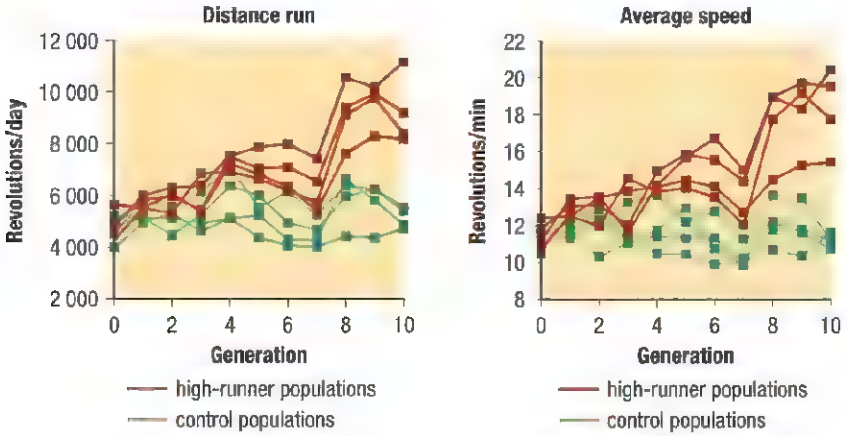


Figure 8 A controlled experiment in mice suggests that some behaviours have a genetic component and can be influenced by directional selection.

This heritable change in mouse behaviour is an example of rapid evolution. It happened quickly—in a matter of 10 generations. While there are many other examples of rapid and observable evolution, most major evolutionary changes are slow, occurring over hundreds of generations and thousands of years. In such cases we can observe the product of the lengthy and ongoing process of natural selection. It is often easy to speculate about the selective pressures that have been at work. **Table 1** provides some examples of well-known animal traits and the selective pressures that have contributed to their evolution.

What is less obvious is how natural selection produces complex structures. Imagining the various stages and selective pressures on species over millions of years is not easy, and unless there is fossil evidence, it may be impossible to know how a particular trait evolved. Nonetheless, it is possible and useful to hypothesize scenarios that led to the evolution of complex features. The following tutorial (next page) presents one such case and challenges you to generate a working hypothesis.

Table 1 Possible Selective Pressures that Resulted in Specific Animal Traits

Animal trait	Selective pressure
hawk: acute vision	• ability to spot prey over long distances
polar bear: white fur	• ability to sneak up on seals on snow-covered ice
elephant: long trunk	• ability to reach for food and water while minimizing the movement of its massive body
lobster: large claws	• ability to crush large shells and other prey items
wolf: keen sense of smell	• ability to locate and track the movements of prey
human: large brain	• ability to reason and communicate • ability to construct and use tools

Tutorial 1 Cumulative Selection

Evolutionary biologists have an extraordinary challenge. They not only study the characteristics of living things, they attempt to unravel how such characteristics came into existence—how they evolved. As part of this process, evolutionary biologists often hypothesize a possible scenario that might have led to the evolution of a particular trait and then look for evidence to support or refute their hypothesis. In this tutorial we will outline a hypothesis for the evolution of insect pollination in plants. This represents one of the most significant adaptations in the history of life on Earth. Insect-pollinated plants are among the most diverse and successful of all living things.

To begin, we must base our hypothesis on a set of assumptions and we must choose an appropriate starting point. We are not attempting to outline the entire evolutionary history of plants themselves, only a particular trait—in this case insect pollination.

Our starting assumptions are as follows:

1. Insect-pollinated plants evolved from simple flowering plants that were wind pollinated. Wind-pollinated plants produce drab, greenish flowers and relatively large quantities of pollen that is not sticky. This is a reasonable assumption given that the simpler non-flowering seed plants—the gymnosperms—are wind pollinated, and modern flowering plants that are wind pollinated have simple flowers that produce large quantities of non-sticky pollen. They are typically small and green in colour.
2. Insects that fed on plants were very abundant during this evolutionary process. Some of these insects fed on flower pollen. This is a reasonable assumption because we know that many different insects visit various flowers and cones and feed on pollen.
3. All new genetic variations must arise from mutation events.
4. A complex adaptation involves a number of different mutations.
5. A mutation must be beneficial if it is to be favoured by natural selection.
6. The process of evolution may take millions of years.

Our evolutionary scenario describes a series of plausible beneficial mutations and the advantage they would have offered the evolving species. Our goal is to present a scenario that meets all of our assumptions.

Evolutionary Scenario

Original plant: wind pollinated flowering plant producing millions of pollen grains; flowers drab and odourless

Original insect: seeks out flowers and feeds on the pollen

Mutation 1: Sticky pollen	Natural selection
• A slight modification of the outer surface of the pollen grains makes the pollen slightly sticky.	• Insects that visit this plant feed on its pollen and get a small amount of pollen stuck to their bodies. • Transported pollen is more likely to reach another flower. • Flowers with sticky pollen have more pollen transferred to other flowers and therefore produce more offspring.

Additional mutations that enhance the sticky quality of the pollen will be favoured for the same reason and over time will accumulate, resulting in sticky pollen.

Mutation 2: Less chlorophyll in flowers	Natural selection
• Flower tissues produce slightly less chlorophyll. • Plant does not rely on flowers for photosynthesis, so this change does not affect food production. • Plant cells contain many pigments; with less chlorophyll the other pigments are slightly more visible.	• Insects are more likely to locate these flowers. • Flowers are more likely to have their sticky pollen carried from one flower to another. • Flowers become more visible to insects and are more likely to receive pollen.

Additional mutations that enhance the colour of flower parts will make them more visible to insects and therefore more likely to be pollinated.

Mutation 3: Hairy insects	Natural selection
• An insect has slightly longer bristles on its body. • Longer bristles are more likely to get covered in sticky pollen.	• Insects are favoured because they are more efficient at pollinating the flowers. • The trait does not benefit the insect directly but increases the success of the flowers they feed on, resulting in a greater food supply.

Additional mutations that enhance the pollen-transferring ability of the insect will favour both the plant and insect.

Additional mutations	Natural selection
• Flower size, colour, or fragrance is enhanced.	• The flower is more likely to attract insects and be pollinated.
• The insect is better able to transfer pollen or find the flowers.	• Insects are more likely to find food.
• The plant has the ability to release small amounts of sap from its flowers. • The earliest rudimentary nectar is produced	• The plant is more likely to attract insects and therefore increase pollination.

Scenario Challenge

With a partner, brainstorm a set of simple mutations and natural selection processes that might have led to the evolution of one or more of the following features:

Binocular vision in primates

Most mammals have eyes set out to the sides and have very poor depth perception but better peripheral vision. Consider what you know about the habitat and behaviour of most primates (**Figure 9**).

Figure 9 Orangutans and other primates have binocular vision.

Poison dart frogs

These colourful frogs are highly toxic and easy to spot (**Figure 10**). Note that both the males and females are coloured, so this is not an example of sexual selection. Consider which feature might have evolved first—coloration or toxicity.

Figure 10 Poison dart frogs are highly toxic.

Bromeliads

Bromeliads are flowering plants that live on other plants (**Figure 11**). They are usually attached to the branches of large trees in tropical rainforests. Their roots are adapted to holding on to branches while their leaves are arranged to form a water-tight basin for catching and holding rainwater.

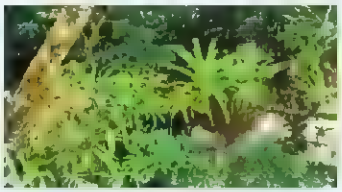


Figure 11 Bromeliad plants capture rainwater in small pools at the base of their leaves.

Evolutionary Change without Selection

Not all evolutionary changes are the result of natural selection. Sometimes, there are changes in the genetic makeup of a population that are not influenced by the traits of individuals. As you will see, each of these changes tends to reduce genetic diversity within a population.

Genetic Drift

The genetic makeup of a population can change simply by chance. When individuals produce offspring, the chances of passing on any particular allele is subject to random chance. The smaller the number of individuals in a population, the greater the influence of **genetic drift**—the random shifting of the genetic makeup of the next generation. In small populations, genetic drift can result in a particular allele becoming either very common or disappearing entirely over a number of generations (**Figure 12**). Any lost alleles result in a net reduction in the genetic diversity of the population.

genetic drift changes to allele frequency as a result of chance; such changes are much more pronounced in small populations

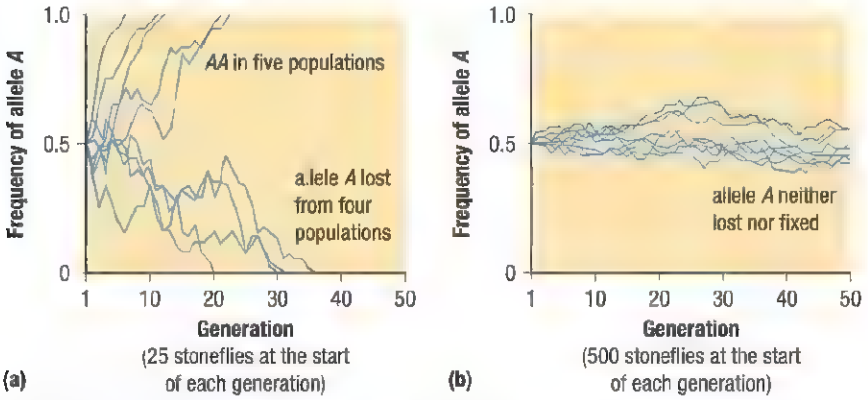


Figure 12 (a) In small populations, genetic drift can result in dramatic changes in allele frequency. (b) In larger populations, genetic drift is not usually significant.

Bottlenecks and the Founder Effect

genetic bottleneck a dramatic, often temporary, reduction in popu ation size, usually resulting in signif cant genetic drift

Genetic bottlenecks result in a loss in genetic diversity following an extreme reduction in the size of a population (**Figure 13**). For example, if an initial population of 10 000 individuals is reduced to only 50 individuals, they are unlikely to contain all of the alleles found in the larger population. Many alleles, and in particular rarer alleles, are likely to be eliminated in this bottleneck event. If the population is allowed to recover, the genetic makeup of future generations will be limited to the alleles carried by those 50 surviving individuals and any new mutations.

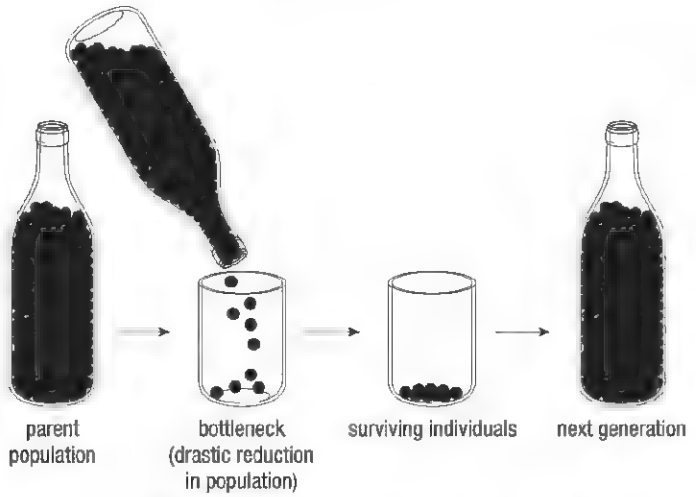


Figure 13 A dramatic reduction in the size of a population can result in a bottleneck. Here, the original population had equal numbers of blue and orange alleles. Following the bottleneck, the blue allele is much more prevalent.

Figure 14 Cheetahs have very little genetic variation because their population was subject to a genetic bott.eneck.

founder effect genetic drift that results when a small number of indiv duals separate from their original population and estab ish a new pop.ulation

Bottlenecks can have adverse consequences for populations. Cheetahs, for example, have very little genetic variability. As a result they are vulnerable to disease. Cheetahs also have low reproductive success and high juvenile mortality rates. All cheetahs are thought to be descendants of a population that experienced a severe bottleneck event—estimated to have left only seven individuals—about 10 000 years ago (**Figure 14**). Similarly, the northern elephant seal population was reduced by overhunting to 20 individuals in the 1890s. Although the population has rebounded to over 127 000 individuals, they are genetically very similar.

The **founder effect** occurs when a small number of individuals establish a new population. For example, a small number of finches from the coast of South America established a founding population on the Galapagos Islands. The initial population would—by chance alone—have a different mix of alleles than the large mainland population. By chance, an allele that was common in the large population might be uncommon in the founding population, or a rare allele might be much more common in the new population. For example, suppose an allele is found in only 1 in 1000 (0.1 %) finches in the mainland population. Now suppose that by chance, 1 of only 20 finches that reach the Galapagos Islands carries the same allele. This represents 5 % of the founding population—an increase of 50 times. While such a change does not increase the diversity of the population, it does mean that the new population will begin with a different gene pool than the original mainland population's gene pool.

Small populations that result from a bottleneck or founder effect are also subject to the effects of genetic drift. This will further increase the chances that their gene pool will differ from that of the original population. Although genetic drift and bottlenecks can be important in some cases, natural selection is usually the major driver behind changes that result in the evolution of a significant adaptation. Natural selection is the only mechanism known that is able to shape a species to its environment.

The Hardy–Weinberg Principle

To modern biologists, evolution is the change in the genetic makeup (or gene pool) of a population over time. Mathematically, a gene pool can be described by the frequency of each of the alleles within the population. Two mathematicians, Godfrey Hardy and Wilhelm Weinberg, used mathematical reasoning to explain the relationships between allele frequencies within a population and the chances of those frequencies remaining constant. This relationship, often represented by a mathematical equation, is referred to as the **Hardy–Weinberg principle.**

Hardy–Weinberg principle In large populations in which only random chance is at work, allele frequencies are expected to remain constant from generation to generation

Any factor that causes allele frequencies to change leads to evolutionary change. Based on the Hardy–Weinberg principle, biologists recognize that the following conditions result in evolution:

- natural selection: favours the passing on of some alleles over others
- small population size: increases the likelihood of genetic drift
- mutation: introduces new alleles to a population
- immigration or emigration: introduces or removes alleles in a population
- horizontal gene transfer: the gaining of new alleles from a different species

These five conditions are known to occur in many populations and inevitably result in evolutionary changes over time. Knowing the influence that each of these factors can have on a population allows biologists to predict which populations are likely to exhibit the most evolutionary change. Biologists must also take into account the particular biology of each species. For example, a species that has high genetic diversity and reproduces very quickly will respond to natural selection more rapidly than a species with little genetic diversity that reproduces very slowly. Such factors account for how insects and bacteria have rapidly evolved resistance to pesticides and antibiotics.

Mini Investigation

Modelling Genetic Drift

Skills: Predicting, Performing, Observing, Analyzing

SKILLS HANDBOOK A2.1

Genetic drift is more likely to occur in small populations. In nature, this may happen when there is a genetic bottleneck and a population is reduced to a small number of individuals. In this investigation you will model how such events can influence the allele frequencies of a population.

Equipment and Materials: containers of "Population A" and "Population B" (pop-it bead organisms); calculator

1. Remove all the individuals from the Population A container. Each individual is represented by two pop-it beads joined together. Each pop-it bead represents a single allele; different colours represent different alleles. Together the two pop-it beads represent the genotype of the individual. For example, heterozygous individuals will contain two different-coloured beads.
2. Without separating the beads, count the total number of each type of allele (bead colour). Record this number as a percentage of the total number of alleles in the population gene pool. These values represent the initial allele frequencies. For example, if there are 50 individuals with a combined total of 20 red and 80 blue beads, then the gene pool contains 100 alleles and the allele frequencies are 20 % red and 80 % blue.
3. Return all the individuals to the container and mix them thoroughly.
4. Without looking, randomly remove 10 individuals from the container. Before doing so, make a prediction about the allele frequencies of a these 10 individuals. These 10 individuals represent the survivors of a bottleneck event (or a small founder population).
5. Count and record the allele frequencies of this population, and then return the 10 individuals to the container.
6. Repeat Steps 3 through 5 twice.
7. Repeat Steps 1 through 6 with Population B.

A. Was there evidence of genetic drift? Did the allele frequencies change when the populations were reduced from 50 to 10 individuals? Were your predictions accurate? K/U

B. Were any changes in allele frequencies consistent? For example, did the allele frequencies of the most common allele always increase? K/U

C. Were any alleles lost in any of the new populations? K/U

D. According to the Hardy–Weinberg principle, there are five conditions that can result in changes in allele frequencies. Which of these conditions were modelled in this investigation? Which were not? K/U T/I

E. Based on your results, do you think genetic drift is likely to cause an increase or a decrease in the genetic diversity of a population? T/I A

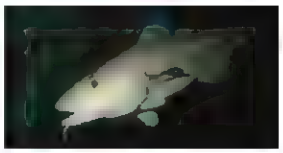
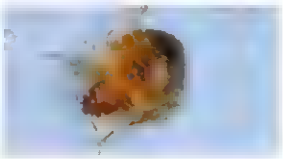
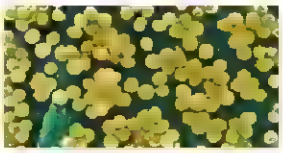
Consequences of Human Influence

UNIT TASK BOOKMARK

Consider how you can apply your understanding of how human activities change the selection pressures of species to your Unit Task.

Humans interact with all other species, either directly or indirectly. We commercially harvest many species from the wild; we alter habitats by clearing land for agriculture, urban expansion, and mining; and we pollute the air, soil, and water. The greenhouse gases we emit are changing Earth's climate and the chemistry of the oceans. We also set aside large areas as parks and intervene to protect endangered species. These interactions act as agents of natural selection and have the potential to influence the evolution of species. **Table 2** describes some consequences of human activities on the evolution of species.

Table 2 Consequences of Human Activities on Evolution

Human selective pressure	Evolutionary change and consequences	Example
• Commercial fishing targets large fish and often allows smaller fish to escape. Some fishing regulations even require the release of small fish. • Fish that reach maturity at a smaller size are more likely to escape and reproduce than individuals that reach sexual maturity at a larger size.	• The average adult size of many valuable commercial fish species, including cod, has declined dramatically. • The alleles that code for large adult size are being lost from the gene pool of the population.	 cod
• Habitat loss, the introduction of invasive species, and overharvesting have reduced the population sizes of many species to extremely low levels. • This has created genetic bottlenecks, reducing the genetic diversity of the species.	• Populations with little genetic variability are less able to survive environmental changes and diseases. • Even if their numbers rebound, populations will not recover their genetic diversity. • The population of northern elephant seals was reduced by hunting to about 20 individuals by the 1890s. The population is now over 127 000, but the seals have very little genetic diversity.	 elephant seal
• Climate change is altering selection pressures on species in many ways. • In some situations changes may happen too rapidly for species to adapt.	• Many migratory bird species are expected to begin migrating shorter distances and eventually stop migrating entirely • Species such as caribou and polar bears living in alpine and arctic environments may not be able to adapt quickly enough to survive.	 caribou
• Selective hunting of prize animals favours individuals with less desirable traits. For example, elephants that grow smaller tusks are less likely to be shot for their ivory. Bighorn sheep that grow smaller horns are less likely to be shot as trophy animals.	• Individuals that exhibit prized traits become less common in the population. • The average tusk size of mature African elephants is decreasing. • Close to 50 % of all male Asian elephants are tuskless. This may have resulted from selective hunting practices in the past.	 Asian elephant
• The use of insecticides and herbicides is widespread. • Resistant insects and weed plants are more likely to survive and reproduce.	• Many insects and plants, such as bedbugs and pigweed, are becoming resistant to pesticides. • The cost of controlling these pests and the health concerns and economic losses they cause are increasing	 bedbug
• The use of antibiotics and antimicrobial cleaners is widespread.	• Many infectious bacteria, such as methicillin-resistant *Staphylococcus aurea* (MRSA), are becoming resistant to multiple varieties of antibiotics, making it more difficult and expensive to treat patients. • Antimicrobial soaps and cleaners rapidly kill off weak bacteria that may be replaced by more resistant forms.	 *Staphylococcus aurea*

8.1 Summary

- Directional and disruptive selection produces evolutionary changes by favouring individuals that differ from the population norm.
- Stabilizing selection acts to limit evolutionary change by favouring the current population norms.
- Sexual selection is a form of natural selection in which traits that specifically enhance mating success are favoured.
- Evolutionary changes produced by natural selection can accumulate over time and result in major adaptations and the formation of new descendent species.
- Genetic drift produces evolutionary changes independently of natural selection.
- Bottlenecks and the founder effect enhance the influence of genetic drift.
- The Hardy–Weinberg principle can be used to identify factors that will result in evolutionary change.
- Human activities have a very strong selective influence on many species and therefore influence their evolution.

8.1 Questions

1. Biologists often describe evolution as a change in the frequency of alleles in a population. How does this definition relate to the process of natural selection? K/U
2. Describe the way in which natural selection has influenced the genetic makeup of Tibetan human populations. K/U
3. Use the sickle-cell allele to illustrate how natural selection can cause a mutation to be beneficial in one environment and harmful in another. K/U A
4. How does evolution favour behavioural traits in males of some species that cause them to risk their life in fights with other males over mates? K/U A
5. Which type of selection led to the following characteristics: K/U
   (a) hollow and very lightweight bones in birds
   (b) hundreds of different but genetically very similar species of fruit flies living in the Hawaiian Islands
   (c) turtles species that have changed little over millions of years
   (d) males of many frog species that call every spring, while females are silent
6. Account for the fact that in stable environments species often show little or no evolutionary change. K/U T/I
7. If species are not changing, is it true to say that natural selection is not happening? Explain your reasoning. T/I
8. Both male and female blue jays are brightly and similarly coloured. Is this an example of sexual selection? Explain. K/U
9. Genetic drift leads to evolutionary change in the absence of natural selection. Explain how this is possible. Provide an example to support your answer. K/U T/I
10. The human population of Iceland was founded by a relatively small initial population more than 1000 years ago. Would you expect the genetic diversity of Icelanders to be more or less than the genetic diversity of Canadians? Explain your reasoning. T/I A
11. Antibiotic-resistant bacteria may expend extra energy and resources to produce special compounds and carry extra genetic material to protect themselves against antibiotics. Predict what might happen to these bacteria if they are not exposed to antibiotics for many generations. T/I A
12. Do online research and complete the following: T/I A
    (a) Describe the key steps that are thought to have occurred in the evolution of eyes. Include labelled diagrams to illustrate the steps
    (b) Have eyes evolved once or more than once in the evolutionary history of life on Earth?
    (c) Explain how having simple or even poor eyesight might be advantageous for a species compared to having no eyesight at all.
13. In each of the following situations, based on the Hardy–Weinberg principle, determine whether or not evolution would be expected to take place. Explain your choice. K/U C
    (a) A very large population of mosquitoes lives in a stable environment.
    (b) A small population of lizards inhabits a remote island
    (c) Climate change influences the flowering time of a species of wildflower.
14. Provide three examples of how human activity is directly influencing the evolution of wild (non-domesticated) species. T/I A

GO TO NELSON SCIENCE

8.2 Speciation

Scientists know that species continuously evolve. This knowledge is based on a wide range of evidence, including the direct observations of evolution in nature and the dramatic examples of change in domesticated species of plants and animals. Changes that occur within species, sometimes referred to as **microevolution**, are often relatively easy to understand. Natural selection favours faster-running cheetahs, colourful displays of male songbirds, and larger brains in humans. But what factors lead to **speciation**—how does an entirely new species evolve? How did cheetahs, giraffes, and humans evolve in the first place?

microevolution changes in gene (allele) frequencies and phenotypic traits within a population and species

speciation the formation of new species

What Is a Species?

A biological species, according to one definition, includes all the members of a population that can interbreed under natural conditions. Individuals of different species cannot interbreed under natural conditions and are described as being reproductively isolated from one another. Populations of different species do not exchange genetic information—they have different gene pools. Defining a species as all members of a population with a common gene pool has advantages.

Evidence of interbreeding between individuals and groups can be difficult or impossible to examine and cannot be applied to species that rarely or never reproduce sexually. Some species are quite distinct from all others and can be readily identified based on their morphology or physical appearance, while two other species might be outwardly indistinguishable from each other. As a result, biologists must employ a variety of methods to help distinguish species.

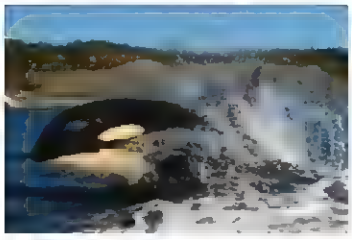


Figure 1 Recent genetic evidence suggests there are at least three species of orcas.

Today the ability of biologists to sample and compare the genetic makeup of different populations has led to some surprising results. Until very recently, orcas were thought to be a single species, but genetic comparisons suggest they represent at least three species (**Figure 1**).

Modes of Speciation

New species can evolve under a variety of circumstances. However, this process always includes the evolution of distinct features that isolate the new species reproductively, and therefore genetically, from other species.

reproductive isolating mechanism any behavioural, structural, or biochemical trait that prevents individuals of different species from reproducing successfully together

prezygotic mechanism a reproductive isolating mechanism that prevents interspecies mating and fertilization (for example, ecological isolation, temporal isolation, and behavioural isolation)

postzygotic mechanism a reproductive isolating mechanism that prevents maturation and reproduction in offspring from interspecies reproduction

Mechanisms of Reproductive Isolation

For a new species to form, individuals from the original species must evolve to become reproductively isolated from the remainder of the population and they must establish a new interbreeding population. A **reproductive isolating mechanism** is any biological factor that prevents the two populations from interbreeding when living in the same region. Reproductive isolating mechanisms can operate in any number of ways. For example, they may be differences in breeding season, physical or behavioural traits, habitat preferences, or the incompatibility of gametes. These are all **prezygotic mechanisms** because they prevent fertilization and zygote formation. Still others, called **postzygotic mechanisms**, can prevent a fertilized egg from growing into a viable and reproducing adult. **Table 1** (next page) lists and provides examples of each of these mechanisms. As you will learn, any mechanism that prevents two populations from interbreeding can give rise to new species, but how do such reproductive isolating mechanisms evolve?

Reproductive isolating mechanisms are often quite subtle, and organisms that appear very similar to each other may not interbreed. Some bird species, for example, are notoriously difficult to distinguish. The willow and alder flycatchers, small songbirds native to Ontario, appear virtually identical and, short of genetic testing, even experts can tell them apart only by their song and the nests they build.

Table 1 Reproductive Isolating Mechanisms

Mechanism	Description	Example
Prezygotic		
behavioural isolation	Different species use different courtship and other mat ng clues to find and attract a mate.	Male frogs of different species have unique calls that attract only females of the r own species.
temporal isolation	Different species breed at different times of the year.	Pussy willows produce flowers in the early spring. They are reproductively isolated from plant species that produces flowers at a different time of year.
ecological isolation	Very similar spec es may occupy different habitats within a region.	The mountain bluebird (*Sialia currucoides*) lives at high elevations, while the eastern bluebird (*Sialia sialis*) prefers lower elevations and does not encounter the mountain species.
mechanical isolation	Differences in morphological features may make two species incompatible.	Male damselflies transfer sperm during an unusual mating flight. The male and female genitalia of each species are unique y shaped and are physically incompatible with other species (**Figure 2**).
gametic isolation	Male gametes may not be able to recognize and fertilize an egg of a different species.	Many marine animals including corals, clams, and sea cucumbers release their sperm and eggs into open water. The sperm recognize eggs of their own species through chemical markers on the surface of the eggs (**Figure 3**).
Postzygotic		
zygotic mortality	Mating and fertilization are possible, but genet.c differences result in a zygote that is unable to develop properly.	Some species of sheep and goat are able to mate, but the zygote is not viable (**Figure 4**).
hybrid inviability	A hybrid individual develops but either dies before birth or, f born alive, cannot survive to maturity.	When tigers and leopards are crossed, the zygote beg ns to develop but the pregnancy ends in a miscarriage or st llborn offspring.
hybrid infertility	Hybrid offspring rema n healthy and v.able but are sterile.	Mules are the sterile hybrid offspring of a horse–donkey cross.

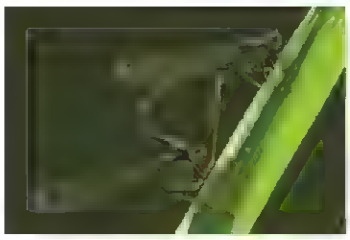


Figure 2 Damselfly individuals of one species are physically incompatible with individuals of other species.

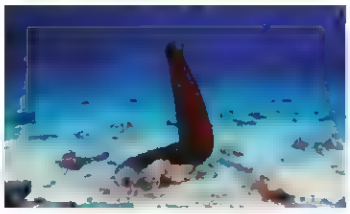


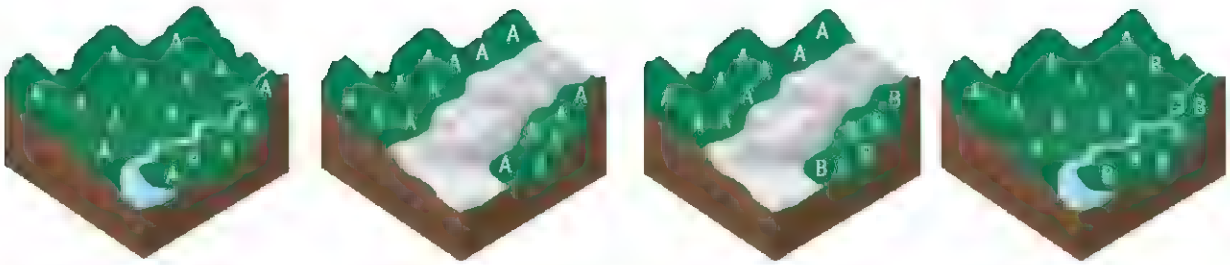
Figure 3 Sea cucumbers have gametic isolation from other marine animals.

Figure 4 The zygote produced by a goat and sheep cross is not v able.

Allopatric Speciation

Most new species form when a single species is separated into two geographically isolated populations. This is called **allopatric speciation**. Once populations are physically separated, they can no longer exchange genetic information. Over many generations the populations will gradually become less and less alike. Any mutation that arises in one population is not shared with the other population. Any differences in the environments of the two populations will lead to different forms of natural selection. Changes that result from genetic drift may also cause the populations to become increasingly different. Once enough time has passed, there is a good chance that the two popula tions will have evolved some sort of reproductive isolating mechanism. Perhaps their courtship rituals will have changed, the time of year they breed or produce pollen will have shifted, or they may no longer be physically compatible.

allopatric speciation the formation of a new species as a resu t of evolutionary changes following a period of geographic iso ation



At first, a population is distrubuted over a large geographical area.

A geographical change, such as the advance of a glacier, separates the original population, creating a barrier to gene flow.

In the absence of gene flow, the separated populations evolve independently and diverge into different species.

When the glacier later melts, allowing individuals of the two species to come into secondary contact, they do not interbreed.

Figure 5 Geographic separation leads to allopatric speciation.

Figure 5 shows how geographical separation can lead to allopatric speciation.

The geographic splitting of a species into two populations can occur in a number of ways. Populations may become isolated on remote islands where they are far from the original population. New selective pressures can then cause them to evolve dramatically new features like that of the flightless cormorant of the Galapagos Islands (**Figure 6**). Mountain ranges may form, separating populations of species whose members do not travel over mountains. Continental drift has split apart entire continents and separated countless species into separate populations.

Figure 6 The Galapagos cormorants lost their ability to fly.

A clear example of allopatric speciation followed the formation of the Isthmus of Panama—a thin strip of land that now separates the Caribbean Sea from the Pacific Ocean. Prior to its formation, the Caribbean Sea was connected by a wide channel to the Pacific Ocean. Many species of marine organisms inhabited this region. Two million years ago, the isthmus formed, permanently dividing species such as the wrasse into separate Pacific and Caribbean populations (**Figure 7**). Now, the species on both sides are distinct and cannot successfully interbreed, even when placed together. Perhaps the best examples are the seven different species of snapper shrimp on each side of the isthmus—each having its closest relative on the other side. Since being separated, 7 original species have evolved into 14 different species.

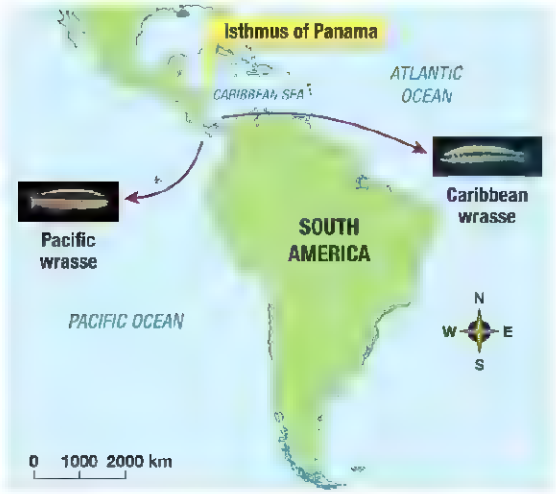


Figure 7 The Pacific and Caribbean wrasse species evolved from a single species that became separated into two populations by the isthmus.

Geologic changes can directly influence the natural selection pressures on species. Consider the effect that the formation of the Rocky Mountains had on the evolution of species. As this mountain range formed, it divided many widely distributed species into separate western and eastern populations and also produced profound changes in their environments. West of the Rocky Mountains, the climate is generally moderate with cool summers, mild winters, and heavy precipitation. East of the mountains, there are hot summers, cold winters, and little precipitation. As a result, the western and eastern populations of the original species experienced different environmental conditions and different selective pressures. Plants, for example, would be selected for their ability to thrive in wet conditions on the coast and arid conditions in the prairies (**Figure 8**). Over millions of years these populations evolved into different species.

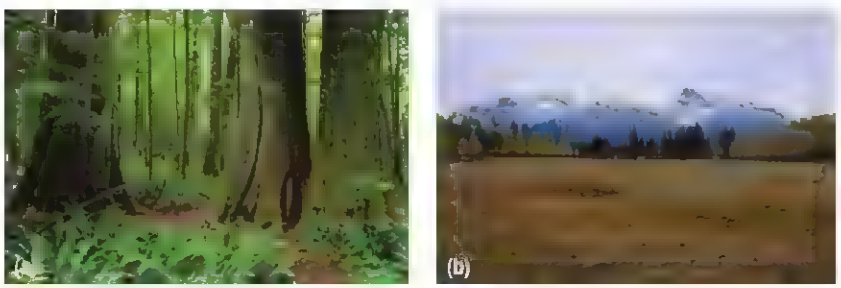


Figure 8 The mountain ranges in Western Canada create two strikingly different environments. (a) On the west coast, natural selection favours species that thrive in a wet, mild climate. (b) On the eastern side of the mountains, natural selection favours species able to survive a dry climate.

A USEFUL ANALOGY

It is often useful, in trying to understand a difficult concept, to consider an analogous process that is more familiar. Understanding speciation is difficult in part because of the long times involved and the formation of isolating mechanisms with which we are unfamiliar. However, consider how the process of speciation is analogous to the formation of a new language. In a non-biological but analogous way, we inherit our language from our parents and pass it on to our children. When a human population becomes geographically separated into two groups, their spoken languages start to diverge. Regional accents and slang develop and spellings change, as do common phrases. New words are also introduced in each population. You have no doubt noticed these differences yourself in the English spoken by people from Australia, England, the United States, and Canada. Given enough time and continued isolation, languages become distinct and individuals from the different regions are no longer able to understand each other. The earliest Germanic language, for example, spoken in northern Europe during the first millennium BCE, has since given rise to more than 50 distinct languages.

Sympatric Speciation

A new species can also evolve from within a large population. This process, called **sympatric speciation**, occurs when individuals within a population become genetically isolated from the larger population. Such isolation may occur gradually or suddenly.

sympatric speciation the evolution of populations within the same geographic area into separate species

One example of gradual sympatric speciation appears to be under way as a direct result of human action. The hawthorn fly is native to North America. The original population of hawthorn flies laid their eggs in the small fruits of hawthorn trees (**Figure 9**). Between 1800 and 1850, after the introduction of apple trees to North America, some of these flies began laying their eggs on apples. Today, the species consists of two populations. One population, now called apple maggot flies, feeds almost exclusively on apples, while the other feeds almost exclusively on hawthorns. Disruptive selection likely favoured mutations that enhanced each feeding behaviour. There is still a small amount of interbreeding between the populations, but they are on their way to becoming reproductively isolated and separate species.

Figure 9 Disruptive selection is resulting in the sympatric evolution of a new species of fly. The original species now consists of two distinct populations. The original form, seen here, mates and lays eggs on native hawthorn fruit. The recently evolved form lays eggs on the fruit of introduced apple trees.

Sudden sympatric speciation is also possible. Even a single mutation can render an individual unable to reproduce with other members of the population. If two such individuals share the same mutation or if a single individual is able to reproduce asexually, a reproductively isolated population, a new species, may result. This is thought to have occurred many times in the evolution of plants. Many plants are able to reproduce both sexually and asexually. If an individual plant has a mutation that prevents successful sexual reproduction, it might still be able to produce large numbers of offspring asexually. These offspring would be sexually compatible with each other.

POLYPLOIDY AND HYBRID SPECIES

Polyploidy can result in sympatric speciation. Mutations causing polyploidy double the number of chromosomes in an individual. Polyploids produce fertile offspring when mated with each other but produce sterile offspring when mated with the original species. The evolution of 30 % to 70 % of all flowering plant species has involved polyploidy. Ontario's eastern gray treefrog (*Hyla versicolor*) is a polyploid species that evolved from the Cope's gray treefrog (*Hyla chrysoscelis*), which is virtually identical in appearance (**Figure 10**). *H. versicolor* is a tetraploid species with four sets of chromosomes ($4n$), while *H. chrysoscelis* is diploid ($2n$). The chromosomes of both species are near-perfect matches, indicating that the eastern treefrog evolved as a result of a polyploidy mutation of the Cope's species.

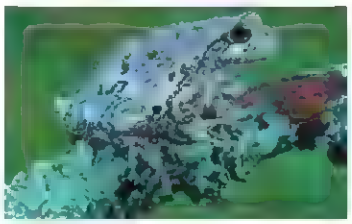


Figure 10 Ontario's eastern gray treefrog is a tetraploid species that is almost indistinguishable from the diploid Cope's gray treefrog.

An interesting quality of polyploids is that they may be fertile when hybridized with other polyploids. This occurs because each of their gametes carries two copies of each chromosome ($2n$), which then act as typical homologous pairs in the hybrid. The hybrid effectively becomes a diploid individual with a mix of chromosomes from two original species. The hybrid can form a new species that will not produce fertile offspring when crossed with either of the two parent species.

Human Influence on Speciation

The separation of a single population into two isolated populations can lead to speciation, but it can also threaten the survival of species. Many human activities, such as agricultural expansion and the construction of roads, are causing once large habitats to be fragmented into smaller areas that effectively isolate populations. A recent study of timber rattlesnake populations in the state of New York revealed that roadways are a significant barrier to gene flow and that genetic diversity within each isolated population was low. Similar research in China has shown that the survival of giant pandas, a critically endangered species, is threatened by their separation into small isolated populations in patches of bamboo forest. Populations with low genetic diversity are at greater risk when threatened by disease or changing environmental conditions such as climate change.

Figure 11 Wildlife corridors prevent isolation, increasing gene flow and maintaining genetic diversity.

These concerns can be addressed by conservation practices. Gene flow can be maintained and enhanced if the connectivity between habitats is ensured. For example, fragmented habitats can be joined by wildlife corridors such as highway overpasses with strips of connecting forest that are left standing (**Figure 11**).

8.2 Summary

- New species can form as a result of the evolution of a reproductive isolating mechanism that prevents members of two populations from interbreeding.
- Populations of the same species evolve independently when separated by a geographic barrier.
- Differences in selective pressures and genetic drift can lead to the evolution of reproductive isolating mechanisms and the formation of new species.
- New species evolve when mutations result in immediate reproductive isolation or when disruptive selective pressures cause one species to gradually separate into reproductively isolated populations.
- Human activities influence the evolution of new species.

8.2 Questions

1. It is not possible to know if two similar fossils represent individuals that were reproductively isolated from each other. Suggest other methods or characteristics that paleontologists might use to determine if two specimens represent different species. K/U
2. Explain which type of reproductive isolating mechanism is at work in each of the following situations: K/U
   (a) Zebroids, the hybrid offspring of matings between horses and zebras, are sterile.
   (b) Asian lions were once common and lived in open grasslands, while Asian tigers preferred forests.
   (c) Female fireflies identify males by the pattern of light flashes they produce. Each species has a unique pattern of flashes.
   (d) Male geese have a penis, while male herons do not. Male herons are unable to fertilize female geese.
   (e) When pollen grains from white pine trees land on the female cones of red pine trees, fertilization does not occur.
3. Plant and animal breeders try to keep their breeding lines "pure" to prevent unwanted crosses with their breeding stock. How is this human activity analogous to the conditions that cause allopatric speciation? K/U T/I
4. Would you expect to find more unique species on a large remote island or on a smaller island that is close to a large continent? Explain your reasoning. K/U
5. How can the separation of two populations lead to
   (a) the formation of a new species?
   (b) a reduction in genetic diversity of the populations and a possible threat to their survival? T/I A
6. An unusual and endangered Tasmanian plant, *Lomatia tasmanica*, is a triploid plant ($3n = 33$ chromosomes) and is completely sterile. It can reproduce only asexually, and all known individuals are genetically identical clones of one another. Fossil evidence suggests this clone has existed for more than 43 000 years. K/U T/I A
   (a) How many chromosomes do you think would be found in the plant species from which it evolved?
   (b) Do you think this species arose by allopatric or sympatric speciation? Explain
   (c) In what way does this plant not fit a typical definition of a species?

Patterns of Evolution

8.3

As you have learned, natural selection leads to predictable outcomes:

- Closely related species share many homologous structures, even though they no longer serve the same function.
- Species have vestigial structures and pseudogenes that once served a useful purpose in their ancestors.
- Remote islands are inhabited by unique species that are descended from a few individuals of species able to reach them across wide expanses of ocean.

When considered on a grander scale, these and other predictable outcomes lead to recognizable patterns.

Adaptive Radiation

Adaptive radiation occurs when a single species evolves into a number of distinct but closely related species. Each new species fills a different ecological niche. This process usually occurs when a variety of new resources become available—resources that are not being used by other species.

adaptive radiation the relatively rapid evolution of a single species into many new species, filling a variety of formerly empty ecological niches

Consider the example of Darwin's finches (**Figure 1**). Here, a group of 13 species that live in the Galapagos Islands evolved from a single species. Let us assume that the original species of finch living on the mainland of South America had a medium-sized bill ideally suited to feed on certain medium-sized seeds. Individuals born with slightly smaller bills might have been better at eating smaller seeds, but they might have faced stiff competition from other bird species that were already specialized in feeding on the smaller seeds. Finches eating larger seeds would also face similar competition. The result

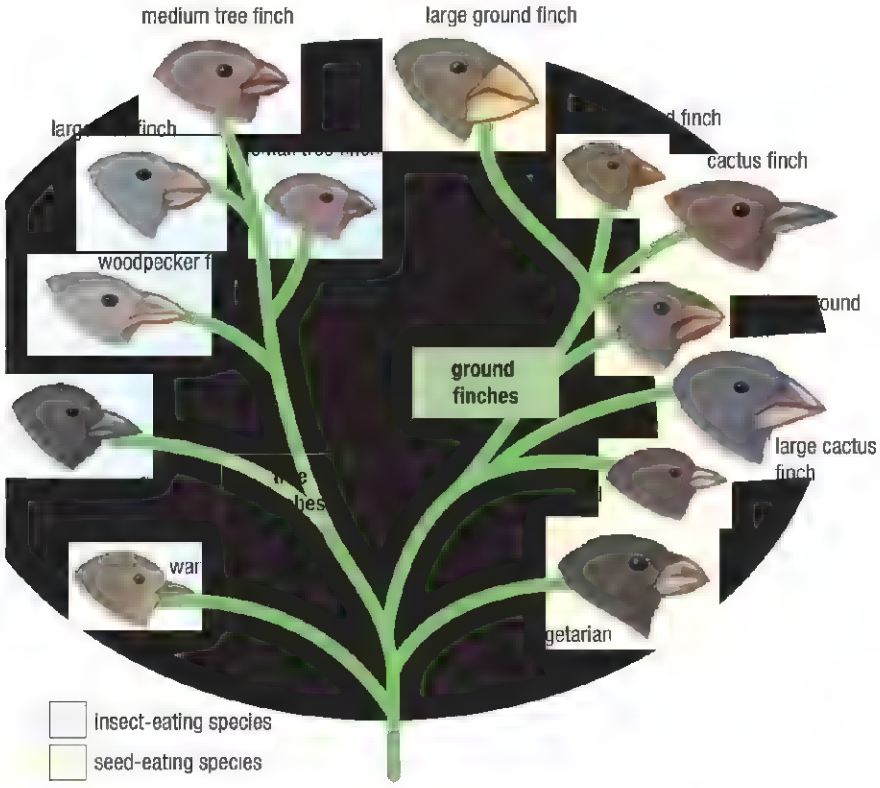


Figure 1 Thirteen species of Darwin's finches are the result of recent adaptive radiation and fill many different ecological niches. Genetic evidence shows they all evolved from a single common ancestor species.

Figure 2 The Galapagos Islands are home to a rich diversity of habitats, from (a) moist forests to (b) dry deserts.

WEB LINK

To learn more about the fascinating evolution of African cichlids,

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was stabilizing selection on the mainland finches to stay in their specialized ecological niche. An entirely different fate awaited individuals of this finch species once they reached the Galapagos Islands (**Figure 2**). Instead of hundreds of other species of land bird, there were few or none. Their only competition was with each other—individuals of the same species—for medium-sized seeds.

The islands might already have been teeming with populations of many plant and insect species that could have arrived long before. The different habitats would have harboured a diverse array of food resources, such as various-sized seeds and different insects. With no insect-eating birds on the islands, the finches had an opportunity to exploit a new food source with no competition. In such a setting, any finches born with a different bill size or feeding behaviour would have been rewarded with a rich supply of food and little competition from other birds. The result of adaptive radiation was seven seed-eating species, one of which feeds primarily on other plant parts, and six insect eating species.

The most spectacular case of adaptive radiation is witnessed in the cichlid fishes of lakes Victoria, Malawi, and Tanganyika in Africa. Each lake is quite isolated from other bodies of water, making it very difficult for new species to arrive. Each lake, however, is home to hundreds of unique species, all descended from one or a few initial species. Lake Malawi alone has nearly 1000 species of cichlid. All but two of these species are found nowhere else on Earth.

In each case of adaptive radiation, an initial species evolves into a variety of new species that differ to varying degrees from the original species. In this way, adaptive radiation contributes to biodiversity. A similar pattern can be seen on a much larger scale when we consider entire groups of organisms and very large ecosystems.

Divergent Evolution

divergent evolution the large-scale evolution of a group into many different forms

In any ecosystem, there are a number of major ecological roles. All natural ecosystems, for example, have producers, consumers, decomposers, and scavengers. These major roles are never filled by a single species. Consider the ecological role of herbivores. Not surprisingly, natural selection has favoured the evolution of a wide variety of herbivores. For example, herbivorous mammals come in a variety of shapes, sizes, and specialties. Natural selection has favoured their **divergent evolution** into a great variety of species. Northern Ontario forests are home to many rodents, the largest taxon of mammals (**Figure 3**). These rodents provide an excellent example of divergent evolution. All of these species evolved from a single common ancestor that existed millions of years ago.

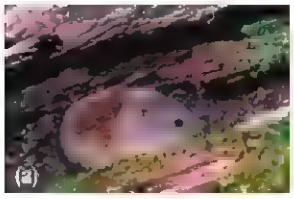

Figure 3 Ontario has over 20 species of closely related rodents, a group of mammals that has undergone significant divergent evolution. Species include the (a) deer mouse, (b) flying squirrel (c) porcupine, and (d) beaver.

Red squirrels have evolved as tree-climbing seed specialists that are active during the day, while northern flying squirrels fill a similar ecological niche but are active only at night. Chipmunks spend much of their time foraging for seeds at ground level. The smallest forest rodents include deer mice and red-backed voles. Deer mice prefer small seeds and insects and usually nest in trees, while voles nest on the ground and eat roots and buds. Porcupines are the largest tree-climbing rodents and feed on twigs and the thin bark of conifers. Beavers, the largest of all Canadian rodents, prefer the twigs and bark of angiosperm species and cut them down and drag them into the water before feeding on them. The unique characteristics of each of these species have proven successful and have been selected for by the environment.

Divergent evolution leads to two predictable outcomes. First, competition between species is minimized as new species diverge to fill specialized ecological niches. Second, given enough time, new species continue to evolve until most available resources are used. The result is an overall increase in biodiversity as a single species or group evolves to fill available ecological niches.

Convergent Evolution

Evolutionary biology predicts that when a single species is placed under two different sets of selective pressures, it is likely to undergo divergent evolution. What if the situation were reversed? What if two species were placed under similar selective pressure? **Convergent evolution** occurs when two *different* species, or taxa, evolve to occupy similar ecological niches. Patterns of convergent evolution are often most obvious when you compare different geographic regions.

convergent evolution the evolution of similar traits in distantly related species

One of the clearest examples is observed in two groups of plants (**Figure 4**). Cacti evolved in the deserts of South America and are native only to the Americas. Euphorbia look similar to cacti, but first evolved in the deserts of South Africa and now occur in Africa, Eurasia, and Australia. Both groups have species with features that have evolved in response to extremely dry conditions. Many cactus and euphorbia species have sharp spines and thick green stems that perform photosynthesis and store water. During dry conditions, some euphorbia have no leaves but, unlike cacti, are able to grow green leaves when ample water is available. Although both plant groups have evolved spines that serve the same protective function, the spines of cacti evolved from leaves, while those of euphorbes evolved from the outward growth of stem tissues.

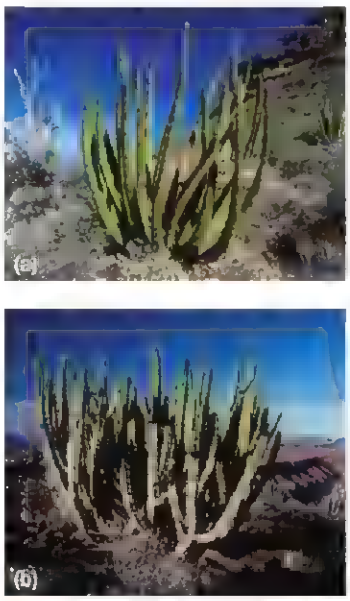

Figure 4 (a) Cacti and (b) euphorbia have evolved similar features in response to their hot dry environments.

Sharks and dolphins are another example of convergent evolution. Both have evolved very similar streamlined bodies well suited for their high-speed carnivorous behaviour. Natural selection favoured the same body shapes in two very distantly related species (**Figure 5**). Sharks evolved from a primitive fish with a cartilaginous skeleton and a side-to-side body motion that powers a vertical tail. Dolphins are recently evolved, warm-blooded marine mammals with a bony skeleton. They power their horizontal tail flukes with an up-and-down motion inherited from their land-living ancestors.

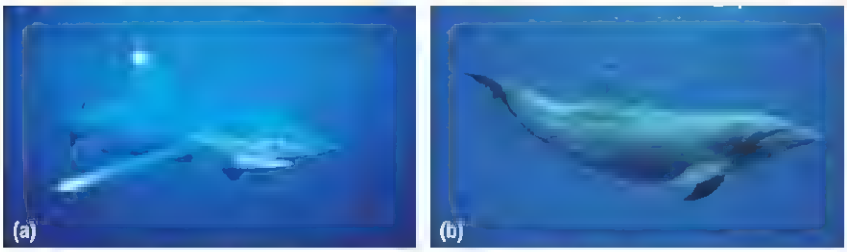

Figure 5 Convergent evolution resulted in the similar body shapes of (a) sharks and (b) dolphins.

Convergent evolution can result in similar features evolving in very distantly related organisms. The selective advantage of detecting and responding to light, for example, resulted in the evolution of a range of light-detecting organs. Protists have simple eye spots, while arthropods, mollusks, and vertebrates have complex and varied eyes (**Figure 6**).

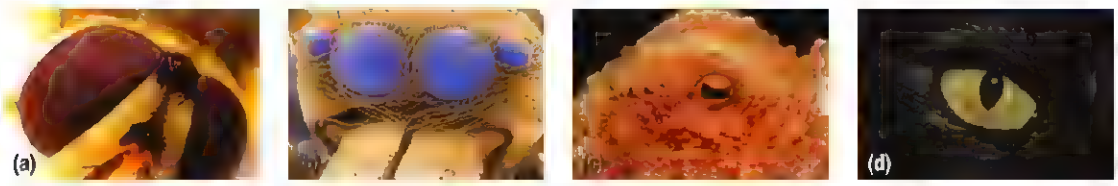

Figure 6 Complex eyes have evolved independently in many animal groups including (a) insects (fly), (b) arachnids (spider), (c) mollusks (octopus), and (d) vertebrates (cat).

Just as the patterns of divergent evolution can be predicted, so can the outcomes of convergent evolution. We can predict two common outcomes. First, natural selection will favour the evolution of similar traits in similar environments. Second, while some traits will converge in form or function, each species will retain other features that provide evidence of their distinct evolutionary past.

Coevolution

coevolution a process in which one species evolves in response to the evolution of another species

A species experiences **coevolution** when its evolutionary success is closely linked to that of another species. For example, certain plants have evolved hard protective shells to protect their seeds, while some seed eating mammals have evolved powerful jaws and teeth for chewing through hard shells (**Figure 7**). Any seeds surrounded by a hard shell might be better protected from herbivores and better able to survive than seeds with thin shells. Similarly, any herbivore with a slightly more powerful jaw might be able to acquire more food than a herbivore with a less powerful jaw. This result is sometimes called an "evolutionary arms race."

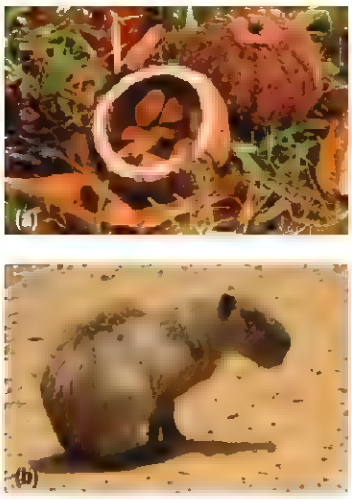

Figure 7 (a) Brazil nut trees have evolved extremely hard protective shells. (b) The agouti is the only mammal with jaws and teeth strong enough to bite open the shell.

As species coevolve, one or both species may become increasingly dependent on the other. In these situations, a threat to one species may be a threat to the other. In extreme cases the extinction of one species can lead to the extinction of the other.

Coevolution is most pronounced in symbiotic relationships. Certain orchid species, for example, are completely dependent on one species of moth to pollinate their flowers. The moths, in turn, depend on the orchid nectar for food. Over time, the flowers of some orchid species have evolved extremely long tubes, called spurs, which contain the nectar. Biologists hypothesize that natural selection has favoured longer spurs because obtaining nectar from a longer spur requires moths to expend more time and effort, making them more likely to pick up pollen. For the moths, natural selection favoured individuals with slighter longer tongues that could reach the nectar at the bottom of the longest spurs. The ultimate result has been the evolution of a most extreme pair. The Madagascar long-spurred orchid has nectar at the end of a 30 cm long spur (**Figure 8**). Its only pollinator, a hawk moth, has a tongue the same length!

Figure 8 (a) The Madagascar long-spurred orchid is pollinated by (b) a hawk moth whose tongue is about 30 cm long.

Research This

Convergent Evolution Down Under

Skills: Researching, Analyzing, Communicating

SKILLS HANDBOOK A2.1, A5.1.

Australia is home to many unique species and is famous for its diversity of marsupials. These unusual mammals include the kangaroo and the koala. Why do so many marsupials live in Australia, and how do they compare to mammals in other parts of the world?

1. Research the marsupials of Australia, considering the following topics:
   - the anatomical differences between marsupial mammals and placental mammals
   - the relationship between the separation of Australia from the Gondwana land mass, and the evolution of marsupial and placental mammals
   - how convergent evolution influenced the marsupial mammals and the placental mammals
   - how introduced placental mammals have become invasive species in Australia

A. Explain how the isolation of Australia led to the evolution of its unique collection of marsupial mammals. T/I

B. Compare the physical appearance and ecological niches of several marsupials to similar placental mammals. For example, compare Tasmanian wolves and grey wolves or flying phalangers and flying squirrels. T/I

C. Outline the current status of invasive mammals in Australia. Which species are of greatest concern? What is being done to try and mitigate the situation? T/I A

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8.3 Summary

- Adaptive radiation increases biodiversity, as a single species evolves into many new species filling a number of different ecological niches.
- Adaptive radiation occurs rapidly when a species is able to exploit a wide variety of new resources with little or no competition from other species.
- Divergent evolution increases biodiversity and leads to predictable large-scale patterns of evolution as major ecological roles are filled by a variety of species—each with their own specializations.
- Convergent evolution occurs when different species or groups evolve similar adaptations under similar conditions.
- Coevolution occurs when the evolution of two species becomes linked. Coevolution often strengthens symbiotic relationships.

8.3 Questions

1. Explain why a species is most likely to undergo adaptive radiation when there is little competition for resources. K/U
2. The Hawaiian Islands are home to about 30 species of very closely related plants called silverswords. Some are tree-like while others are dwarf shrubs. They are found nowhere else on Earth. Use your understanding of adaptive radiation to describe their likely evolutionary past. K/U T/I
3. Compare and contrast divergent and convergent evolution. Include examples to illustrate the similarities and differences. K/U
4. Many species of fish and waterfowl are darker on their upper surface and lighter coloured below. T/I
   (a) What pattern of evolution is most likely at work?
   (b) Suggest possible selective advantages for this coloration.
5. Most remote oceanic islands have at least one unique species of flightless bird that shows little or no fear of humans or other large predators. Account for this observation. T/I A
6. As dolphins swim, they arch their backs with an up-and-down motion of their tail flukes. Land mammals such as horses use a similar arching motion as they run. Fish, however, use a side-to-side motion to move their tails. Do online research to find out how amphibians and reptiles flex their backbones as they move. T/I
7. Snakes are not the only legless terrestrial vertebrates. Caecilians are a group of amphibians that also lack legs (**Figure 9**). Is this an example of convergent or divergent evolution? Explain your reasoning.

Figure 9

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8.4 Explore an Issue in Evolution

SKILLS MENU

- Defining the Issue
- Researching
- Identifying Alternatives
- Analyzing
- Defending a Decision
- Communicating
- Evaluating

Figure 1 The dodo was a large flightless bird that evolved on the island of Mauritius in the Indian Ocean. It became extinct in the seventeenth century. Pigs, monkeys, cats, dogs, and rats, all introduced to the island by humans, fed on the dodo eggs and young. Humans destroyed their habitat and hunted them for food.

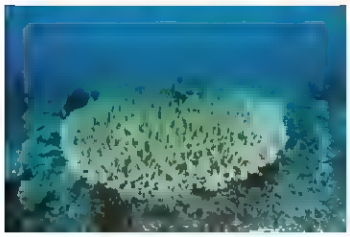

Figure 2 Corals are threatened by pollution, warming waters, and changes in ocean acidity. It is extremely difficult for a species to adapt to multiple environmental stresses that occur quickly.

Avoiding Extinctions

New species evolve and living species become extinct (**Figure 1**). The rates at which these changes take place vary. Over the entire history of Earth, the rate of species formation has been, on average, greater that the rate of extinction. The result is that over billions of years the long-term trend has been a gradual increase in the number of species on Earth. This general trend, however, has been sharply reversed on at least five occasions, when mass extinction events have taken place. Mass extinction events occur on a global scale and are biologically traumatic. The diversity of life on Earth plummets.

Each past mass extinction event has been followed by the recovery of species diversity over a period of millions of years. While such recoveries might be considered rapid from the perspective of geological time, they are extremely slow from the perspective of a human lifetime.

Past mass extinction events were caused by actions that altered Earth's biosphere in a profound way. An asteroid impact or a series of large volcanic eruptions can cause sudden and profound changes in the chemical composition of the oceans and atmosphere. They can lead to rapid climatic changes that wipe out species before they are able to adapt.

Today, biologists around the world are deeply concerned about the increasing rate of species extinction. The primary threats to species are habitat loss and degradation, the introduction of invasive species, overharvesting, pollution, and climate change — all caused by humans. The situation has reached critical levels for many species. Some biologists estimate that without concerted action and international cooperation, more than half of all plant and animal species on Earth could be extinct within 100 years. The rate of extinction is on a par with extinctions in Earth's past. Consider some statistics from the International Union for the Conservation of Nature (IUCN) on threatened species:

- Primary forests are being lost at a rate of 6 million hectares per year.
- Present extinction rates are estimated at 1000 times the natural rate.
- About 70 % of the world's coral reefs are threatened or severely damaged.
- An estimated 22 % of all plant species are at risk.
- Of 47 677 species that have been assessed, 17 291 are in danger of extinction.

The Issue

A number of human activities are causing rapid acceleration in the rate of species extinction (**Figure 2**). These activities pose a serious threat to the biodiversity of life on Earth and the sustainability of natural ecosystems.

Role

Your group's goal is to investigate this issue from the perspective of an evolutionary biologist. You will examine the influence that human activities are having on the ability of species to adapt to change by natural evolutionary processes.

Audience

Your audience will be members of the IUCN, whose mandate is to help the world find pragmatic solutions to environmental challenges. The IUCN also maintains the Red List of Threatened Species.

Goal

You will investigate the ways in which environmental changes resulting from human activity undermine the ability of a species to evolve and adapt. You will assess how such changes increase the likelihood that species will become extinct. You will then present your assessment of these changes, including a set of recommendations to avoid or mitigate them. Focus on the following human-caused environmental changes: habitat loss and fragmentation, the introduction of exotic species, modern agricultural practices, and climate change.

Research

As you research each type of environmental change, consider each of the following relationships to the species of concern:

- How does the pace of change compare to the speed at which threatened species are able to evolve?
- What influence is the human action having on the genetic diversity of the threatened species? Is there a risk of causing a genetic bottleneck?
- How do new conditions compare to the conditions under which threatened species evolved?
- What actions can be taken to reduce or eliminate the negative impacts of these changes?

Identify Solutions

- Consider ways of halting or reversing the human actions that are responsible for threatening species.
- Consider alternatives that do not reduce the ability of a species to evolve.
- Identify actions that might enhance the ability of a threatened species to adapt to new environmental conditions (**Figure 3**).

Figure 3 Building and installing a bat box is a simple and effective way to increase habitat for these threatened species.

Make a Decision

Decide on a set of recommendations that you will present to the IUCN panel.

Communicate

In your presentation, include specific examples of human impacts and possible evolutionary consequences that have the potential to lead to the extinction of species and loss in biodiversity. In presenting your recommendations to the panel, explain how your recommendations will specifically enhance the evolutionary potential of species to adapt to change.

Plan for Action

Extinction Is Forever

Choose a species that is currently threatened with extinction. It may be a local species or a species in a different part of the world. Research the specific human actions that are responsible for its current status. Investigate the ways in which an individual could help this species adapt to environmental change. Consider your set of recommendations from this Explore an Issue activity as well as others specific to your chosen species.

Prepare a plan of action that an individual could follow in order to benefit this species. In your plan, include

- specific physical actions, such as habitat improvements, that an individual could carry out
- a list of organizations involved in conservation initiatives in support of the species
- a list of government agencies and/or officials you could contact in order to voice your concerns
- sources of information about this species that could be shared with friends, family, and the public

GO TO NELSON SCIENCE

8.5 Macroevolution

The history of life on Earth has been one of continual evolutionary change. From simple beginnings, life on Earth has become more diverse and more complex over time. The original single-celled ancestors of all living things have given rise to the millions of species that are alive today, as well as to the many millions that have become extinct. In this section you will explore factors that influence these large-scale processes of **macroevolution** in more detail and learn how biologists use evidence to infer the evolutionary relationships between different species and groups.

macroevolution large-scale evolutionary changes including the formation of new species and new taxa

The Tree of Life

The simplified tree of life in **Figure 1** depicts the evolution pathways of some of the major branches of living organisms. The diagram raises an obvious question: how did life begin? Or, alternatively, how did the first cell originate? The study of **abiogenesis**, the formation of life from non-living matter, is being actively researched. There are many fascinating and competing theories. It is known, for instance, that many of the key building blocks of life, such as amino acids, hydrocarbon chains, and other simple organic molecules, can form under natural conditions. Some even occur in space and are compounds within comets. It is also known that some RNA molecules are capable of replicating themselves, independent of any other cell components. RNA molecules are strong candidates for the first self-replicating precursors to living cells. The challenge to scientists who study abiogenesis is to conceive of all the physical and chemical situations that may have existed on Earth billions of years ago.

abiogenesis the origin of life from non-living matter

WEB LINK

To learn more about the current theories and evidence regarding abiogenesis,

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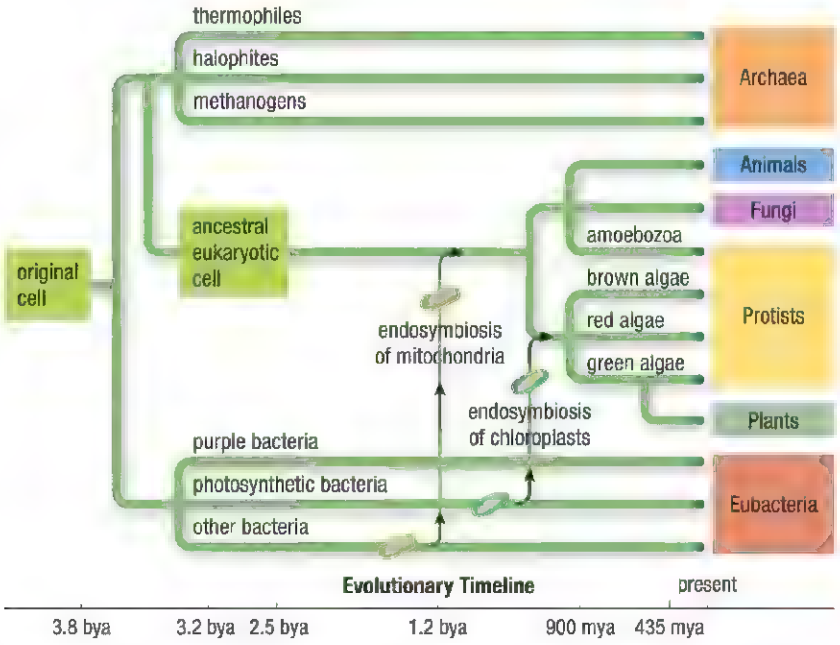

Figure 1 Simple single-celled life has existed on Earth since at least 3.5 billion years ago (bya). Eukaryote evolution occurred much later and involved a number of endosymbiosis events (two are shown here). By 500 million years ago (mya), eukaryote evolution had given rise to the great diversity of complex multicellular organisms

There are many competing theories about the origin of the very first cells. Scientists, however, are now convinced that life has existed on Earth for more than 3.5 billion years and has been evolving ever since. It took more than 2 billion years for eukaryotic organisms to evolve and another several hundred million years for multicellular life forms to evolve. While single-celled organisms are very small and simple, multicellular organisms evolved into a great diversity of forms.

Diversification and Mass Extinction

At one time dinosaurs dominated Earth's terrestrial ecosystems. These reptiles, some of which were enormous, first evolved some 250 million years ago and began to diversify and flourish about 200 million years ago. For more that 100 million years, dinosaurs were the dominant vertebrate herbivores and carnivores on land. Despite all their success, however, the dinosaurs' reign ended abruptly with a now famous mass extinction event 65 million years ago (**Figure 2**). The only surviving descendants of the dinosaurs are birds.

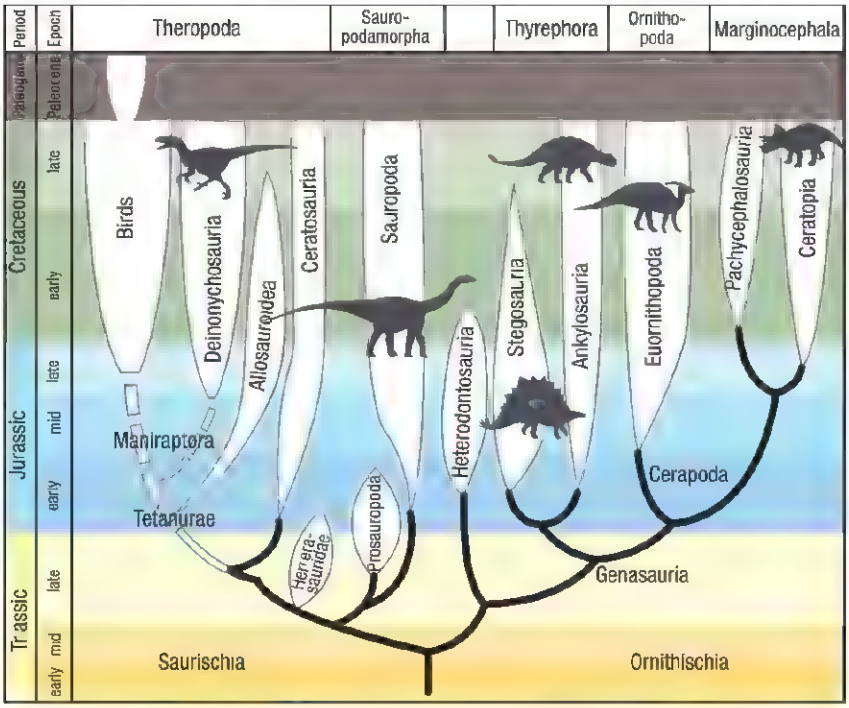

Figure 2 The early dinosaurs branched into two major clades—the Ornithischia and the Saurischia. The Ornithischia include the stegosaurs, triceratops, and duck-billed dinosaurs, while the Saurischia include the massive sauropods, the famous *Tyrannosaurus rex*, and the birds.

While the dinosaurs themselves were a truly remarkable group of animals, their evolutionary history of successful diversification followed by mass extinction is by no means unique. As you learned in Section 8.3, groups of organisms often undergo a period of divergent evolution as they evolve to fill ecological niches. In the case of the dinosaurs, this led to the evolution of more than 300 known species and perhaps many more.

Although individual species may become extinct for a variety of reasons, what could cause the sudden disappearance of so many otherwise successful species? The strongest evidence for the cause of this mass extinction 65 million years ago is the asteroid crater located on the edge of the Yucatan peninsula (**Figure 3**). The crater is almost 10 km deep and 200 km in diameter. Some theorize that the asteroid would have been moving at about 160 000 km/h and would have blasted 200 000 km^3 of vaporized debris and dust into Earth's atmosphere. The energy released by the impact would have produced a wave of super-heated air capable of killing all life on land for thousands of kilometres. Tsunamis 120 m high would have inundated coastlines around the world, and smoke and dust would have blocked most sunlight for months. The resulting cold temperatures would have had devastating consequences for countless species. Recent findings suggest multiple large impacts may have occurred over a period of several thousand years.

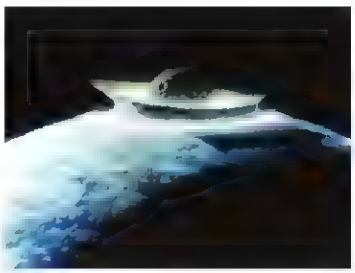

Figure 3 The extinction of most species of dinosaurs 65 million years ago is thought to have been caused by a large meteorite impact.

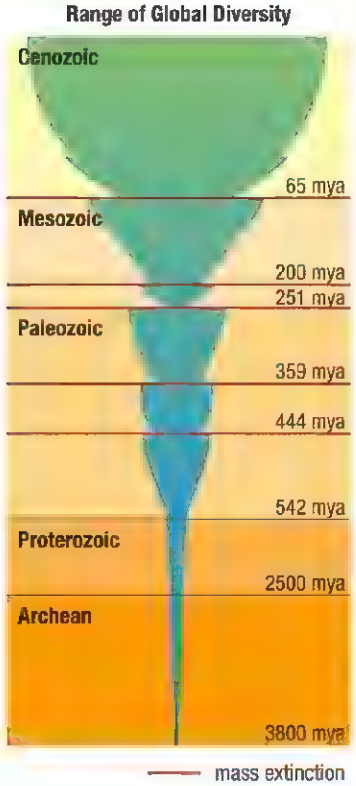

Figure 4 The history of life on Earth is characterized by increasing diversity interrupted by a number of sudden mass extinction events, five of which were particularly dramatic.

Cambrian explosion the rapid evolution of most major animal phyla that took place over approximately 40 million years during the Cambrian period

Earth's history is divided into five eras based on dramatic changes in the fossil record. Notice the trend of ever-increasing diversity interrupted by sudden extinction events (**Figure 4**). The Palaeozoic era, for instance, begins with the Cambrian explosion about 542 mya and ends with the most massive extinction event in Earth's history. The **Cambrian explosion** is so called because it was the time during which most major groups of animals first evolved and underwent rapid diversification. Around 251 million years ago, a series of cataclysmic events eradicated more than 90 % of known marine species. Although uncertainty remains about the cause of the extinction event, many scientists suspect that massive tectonic movements accompanied by volcanoes and rapid climate change played a primary role.

A cataclysmic event is not needed to cause an extinction. Perhaps surprisingly, even the five major mass extinction events since the Cambrian explosion account for only about 4 % of all extinctions that took place during this time.

As you are aware, the current rate of species extinction, due almost entirely to the actions of humans, is very high.

Cladistics and Phylogeny

Cladograms are used to illustrate the evolutionary relationships, or phylogeny, of different groups of species of organisms. The cladogram in **Figure 5**, for example, shows the phylogeny of some major groups of vertebrates. By examining a cladogram, one can infer which groups are more closely related and the general sequence of events that gave rise to each group. In this example, Species A is the most recent common ancestor shared by all groups, while Species B is a common ancestor to all groups except the ray-finned fish. Species C gives rise to the mammals and to a clade that includes all living and extinct reptiles. The cladogram also indicates that birds and crocodiles are closely related, sharing the most recent common ancestor of any two groups (Species E).

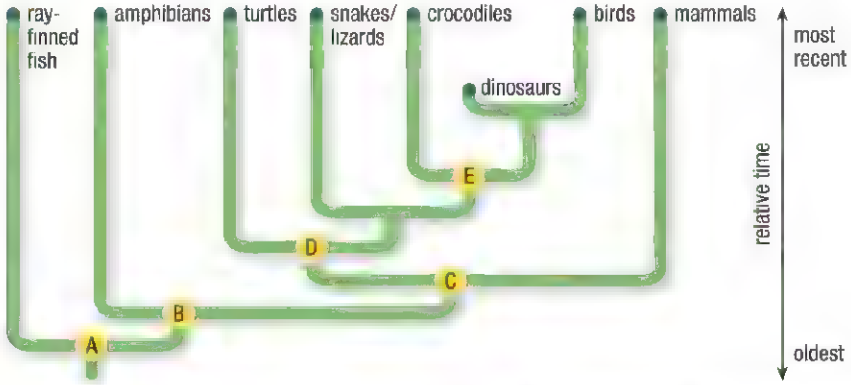

Figure 5 Cladograms show the evolutionary relationships between groups of organisms. Letters at branching points represent the most recent common ancestor of groups that arise beyond that point.

cladistics a method of determining evolutionary relationships based on the presence or absence of recently evolved traits

derived trait a trait that has evolved relatively recently with respect to the species or groups being discussed

synapomorphy a derived trait shared by two or more species or groups

Phylogenies are based on a careful evaluation of a wide range of evidence, including the fossil record, morphology, and genetics. The most widely accepted method of applying this evidence is called cladistics. **Cladistics** uses the presence or absence of recently evolved traits, or **derived traits**, as the key to determining how closely two groups are related. Two groups that share a recently evolved trait, a **synapomorphy**, are thought to be more closely related to each other than to groups that do not share the trait. For example, all birds have feathers and are more closely related to each other than to reptiles without feathers. Only the recently evolved form of a trait is useful for grouping. Consider, for example, the presence or absence of a tail as a feature for grouping vertebrates. Salamanders and howler monkeys have long tails, but apes, such as chimpanzees and gorillas, do not. It would be an error to think that because howler monkeys have tails they are more closely related to salamanders than to apes. Instead, the evolutionary loss of a tail is the more recently derived trait and therefore can be used as evidence that chimpanzees and gorillas are more closely related to each other than to monkeys or salamanders.

The key to cladistic analysis is to make inferences based on synapomorphies. Unfortunately, evolutionary changes can make this challenging. Some suspected synapomorphies may be lost, while others may turn out to be false. All mammals, for example, have evolved from ancestors with hair, but whales have lost their hair. So the presence of hair is an ideal synapomorphy for distinguishing most but not all mammals from other vertebrates. Humans and birds both walk on two legs, but this trait evolved independently, among both our ancestors and those of birds. In this case we must consider these two instances of bipedalism as separate traits.

Biologists are able to apply the science of cladistics to large numbers of related organisms and determine their phylogenetic relationships, based on synapomorphies. They use advanced software programs and large data sets from many sources that include a wealth of genetic information. This science is extremely valuable in understanding the evolution of new strains of disease-causing viruses and micro-organisms. Cladistic analysis of human immunodeficiency viruses (HIV), for example, reveals that closely related but distinct strains have evolved from an original SIV (simian immunodeficiency virus) and have jumped from chimpanzees and monkeys to humans on five separate occasions.

Tutorial 1 Constructing Cladograms

Sample Problem 1: Creating a Cladogram

Use the morphological evidence presented in **Table 1** to construct a cladogram. Based on the cladogram, describe the phylogeny of the organisms.

Table 1 Morphological Data

Animal	Characteristics			
	Digits	Skin surface	Forelimbs	Tail
lemur	five digits	hair	grasping hands	present
deer	two digits	hair	non grasping	present
cow	two digits	hair	non-grasping	present
chimpanzee	five digits	hair	grasping hands	absent
human	five digits	hair	grasping hands	absent
lizard*	five digits	scales	non-grasping	present

*One group must be included as an "outgroup." An outgroup is a group that is not closely related to the groups of interest and therefore unlikely to share any recent traits with other groups. In this case a lizard was chosen as a distantly related vertebrate.

Solution:

Step 1. Consider each characteristic and judge which trait is the more recently derived trait. This can usually be done by comparing the traits with the outgroup.

In this case we make the following inferences:

- Two digits on each foot is a derived trait (having five digits is the primitive condition).
- Having hair is a derived trait (having scales like reptiles and fish is a primitive condition).
- Having grasping hands is a derived trait (having four non-grasping "feet" is the primitive condition).
- The lack of a tail is a derived trait (having a tail is the primitive condition).

Step 2. Create a table of synapomorphies (shared derived traits) (**Table 2**).

Table 2 Synapomorphies

Animal	Synapomorphies—shared derived traits			
	Two digits	Hair	Hands	No tail
lemur	–	+	+	–
deer	+	+	–	–
cow	+	+	–	–
chimpanzee	–	+	+	+
human	–	+	+	+
lizard	–	–	–	–

Step 3. Draw a "V," with the outgroup at the upper left (**Figure 6(a)**). The base of the V represents the common ancestor to all animals.

Step 4. All the animals except the lizard share the feature of having hair. We can indicate the evolution of hair on the right branch leading away from the lizard (**Figure 6(b)**).

Figure 6

Step 5. The remaining animals fall into two groups—those with two digits and those with grasping hands. We therefore split the right branch into two and locate the evolution of these traits above the split (**Figure 7(a)**). We can divide the deer/cow branch in two and place the name of an animal at the end of each branch.

Notice that when you split a branch, the choice of left or right branch for positioning the groups is arbitrary. We could have chosen to place the deer/cow lineage on the left rather than on the right.

Step 6. The chimpanzee and human both lack a tail, so we create a new branch and locate this derived trait above the split. (**Figure 7(b)**). Label the ends of the remaining branches.

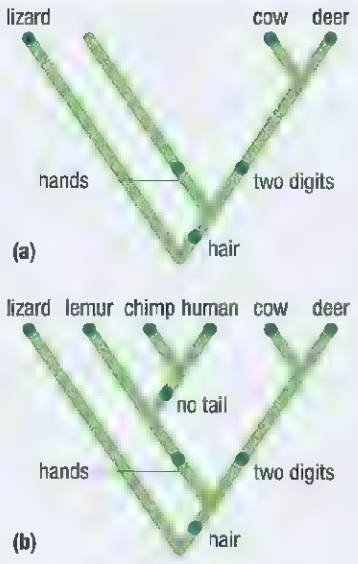

Figure 7

Conclusion:

Based on the completed phylogeny, we can infer that the cow and the deer are more closely related to each other than to other groups. Similarly, humans and chimpanzees are more closely related to each other than to other groups. We can also conclude that lemurs are more closely related to chimps and humans than to cows and deer.

Practice

1. Use the morphological evidence presented in **Table 3** to construct a cladogram. Based on the cladogram, describe the phylogeny of the organisms.

Table 3 Morphological Data

Animal	Characteristics			
	Mouth opening	**Skin surface**	**Respiratory organ**	**Bony limbs**
lungfish	jaw	scales	lungs	absent
turtle	jaw	scales	lungs	present
robin	jaw	feathers	lungs	present
pike	jaw	scales	gills	absent
lamprey*	no jaw	scales	gills	absent

*The lamprey has been chosen as the outgroup.

Investigation 8.5.1

Looking for SINEs of Evolution (page 367)
You can now complete Investigation 8.5.1. In this controlled experiment you will use genetic data to reveal the evolutionary relationships of whales.

Gradualism and Punctuated Equilibrium

Another topic of great interest to evolutionary biologists is the pace of evolution. How quickly do new species and entirely new groups evolve? How long, for example, did it take birds to evolve from their reptile ancestor? And how quickly can existing species adapt to changes in their environment? Answers to these questions have significant implications. Knowing the answers might allow us to judge how species will respond to climate change and other human-influenced impacts on the environment.

Biologists know that at the level of individual species, some evolutionary changes can be quite sudden. For example, a single mutation causing polyploidy can give rise to a new species. Alternatively, other changes, such as the evolution of the giraffe's long neck, have occurred gradually over a period of millions of years. Biologists have proposed two theories to explain the patterns of evolution that take place over very long periods of time.

The **theory of gradualism** states that as new species evolve, they appear very similar to the original species and only gradually become more distinctive (**Figure 8(a)**). Over long periods of time small changes accumulate, resulting in dramatically different organisms. If this theory holds true for all or most species, we would expect to find this pattern in the fossil record, with many fossil species representing changing transitional forms. The fossil evidence of whale and horse evolution, for example, illustrates this pattern of gradual change over millions of years (**Figure 9**).

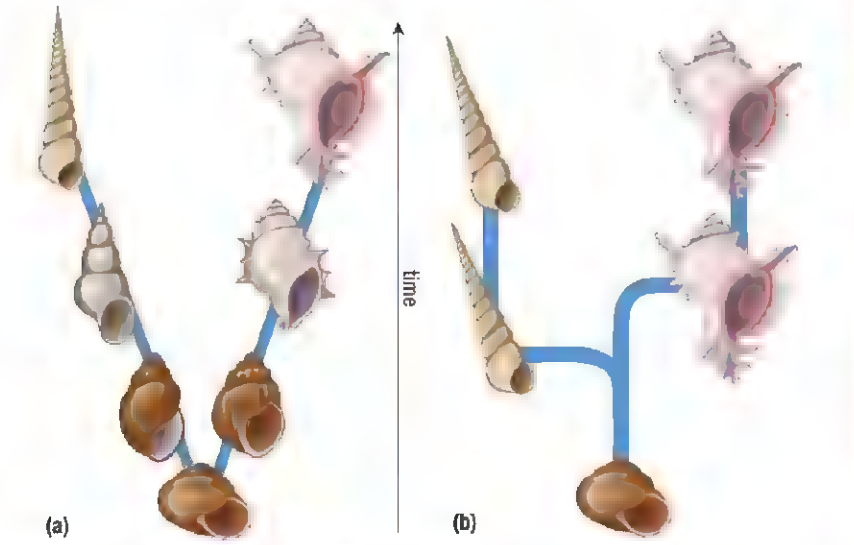

Figure 8 (a) The theory of gradualism suggests that most evolutionary changes are gradual. (b) The theory of punctuated equilibrium proposes that most evolutionary changes are abrupt.

In many other cases, however, this is not the case. Instead, the fossil record often shows new species appearing quite suddenly and then remaining little changed over long periods of time. A theory to account for this pattern was proposed by Niles Eldredge of the American Museum of Natural History and Stephen Jay Gould of Harvard University. Their alternative **theory of punctuated equilibrium** suggests that the process of evolution is slow, but is occasionally punctuated by periods of rapid change (**Figure 8(b)**). The theory of punctuated equilibrium consists of three main assertions:

- New species evolve rapidly in evolutionary time.
- Speciation usually occurs in small isolated populations and therefore leaves behind few transitional fossils.
- After the initial burst of evolution, additional changes are very slow.

It is now widely accepted that both gradualism and punctuated equilibrium play a significant role in evolution. In situations where the environment changes slowly, evolutionary changes would likely be gradual. In contrast, when a species is exposed to new or rapidly changing environmental conditions, we can expect rapid evolution. After a mass extinction event, for example, species that do survive enter an environment with far fewer competitors.

Gaps and Missing Links?

Our scientific understanding of the world around us is incomplete. There are many significant gaps in our knowledge of biology, chemistry, and physics. If this were not the case, there would be no need for future scientific research. If we knew everything about chemistry, research chemists would be out of work. If we knew everything about disease, medical research would be unnecessary. But this is not the case. In fact, scientific research is more active than it has ever been in human history. As our scientific knowledge has grown, so has the number of research scientists looking for answers to new questions.

theory of gradualism a theory that attributes large evolutionary changes in species to the accumulation of many small and ongoing changes and processes

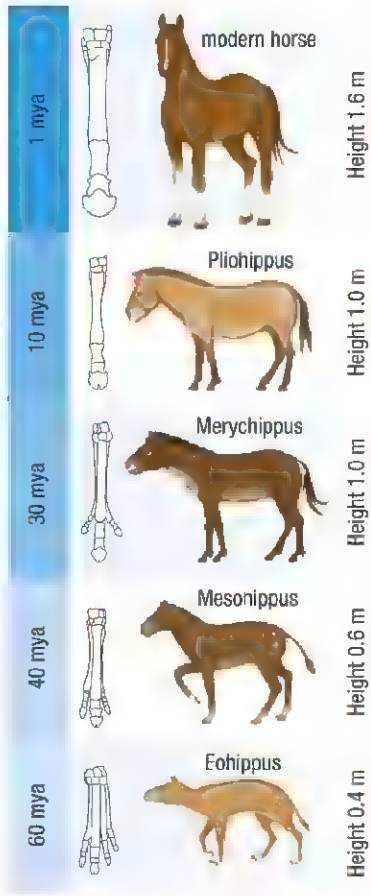

Figure 9 The ancestors of the horse include many intermediate forms between small four-toed mammals and the present-day single-toed horse. The complete fossil record also reveals a highly branched tree with many species.

theory of punctuated equilibrium a theory that attributes most evolutionary changes to relatively rapid spurts of change followed by long periods of little or no change

LEARNING TIP

Theories and Gaps

Missing information or a lack of understanding does not undermine knowledge and theories that are supported by other evidence. Historians, for example, will never know all of the events that took place leading up to and during the War of 1812, but they do know that the war took place and have great confidence in their knowledge of many of the details. The same is true in science.

transitional form a fossil or species intermediate in form between two other species in a direct line of descent

Figure 10 The fossil of *Archaeopteryx* shows features that are clearly transitional between those of a reptile and a bird.

A commonly held misconception is that a gap in our scientific understanding reflects scientific uncertainty over the underlying theory. The misconception is often expressed in this form: "if scientists cannot explain how X happened, or have still not discovered Y, then their theory must be weak or flawed." Such gaps, however, should not cause uncertainty in a scientific theory. Chemists had great confidence in the validity of the periodic table of the elements long before it was complete. Our understanding of atomic theory, evolution, and quantum theories are incomplete but are not in any scientific doubt. These theories account for much of what we do know, and they are in agreement with an extraordinary wealth of evidence.

In evolutionary biology, a key source of evidence is the fossil record. The fossil record, however, is not complete—there are many gaps. Species with delicate bodies do not fossilize readily, and many species do not live in environments where the conditions for fossilization occur. In Darwin's day, evolutionary biologists had a very limited fossil record. There were few fossils of **transitional forms** organisms intermediate in form between their modern forms and their ancient relatives. These gaps in the fossil record were referred to as "missing links." For example, there were no fossils of early land animals to offer direct evidence of life invading the land. There were no fossils of early birds showing the beginnings of feathers and flight. Darwin knew that a lack of evidence was not evidence against his theory and that an understanding of evolution would enable biologists to make predictions about these transitional forms.

Today there is a wealth of fossil evidence, and many of the initial missing links between major groups of organisms have been filled. The first and most famous fossil of a transitional species was that of *Archaeopteryx* (**Figure 10**). This species had features of both birds and more primitive reptiles. It had a bony jaw with teeth and a long bony tail, but also feathered wings. Many more ancestral bird fossils are now being unearthed in China. With these fossils, we are learning about the evolution of flight.

Another gap has been filled with a series of fossils of early whales found in Pakistan (**Figure 11**). The discovery of the fossilized skull of *Aetiocetus* filled a missing link between the early ancestors of whales with nostrils on the end of their snout, and modern whales with nostrils on the top of their head. The nostrils of *Aetiocetus* are "halfway" between and provide an excellent example of a transitional fossil.

Figure 11 *Aetiocetus* is the transitional form between modern whales and their ancesters.

8.5 Summary

- The history of life on Earth follows a general trend toward increasing diversity marked by rare mass extinction events.
- Cladistics uses the occurrence of shared derived traits to infer evolutionary relationships.
- The theory of gradualism proposes that most evolutionary changes occur over long periods of time.
- The theory of punctuated equilibrium proposes that major evolutionary changes happen relatively rapidly and are then followed by long periods of little change.
- All scientific understandings are incomplete. Scientific investigations continue to fill these gaps.

8.5 Questions

1. Many scientists believe that at one time conditions on Mars may have been suitable for the evolution of life. Use the Internet and other sources to learn about any evidence that supports the possibility of past or present life on Mars or other planets. K/U T/I A
   (a) Define abiogenesis.
   (b) Why is abiogenesis considered to be distinct from evolution?
   (c) Suggest ways in which the same principles of natural selection might have influenced the formation of chemicals and the very first cell-like structures.
   (d) What evidence suggests that life might have been possible on Mars in the distant past?
2. In what way was endosymbiosis critical for the evolution of animals, plants, and fungi? K/U
3. You hear a scientist describe the history of life on Earth as one of both increasing diversity and mass extinction. Explain this statement using a diagram to illustrate the relationsh p between these opposing processes. T/I A
4. Some scientists suggest that without the mass extinction of the dinosaurs, mammals would not have been able to undergo adaptive radiation. Use your understanding of competition for resources to support or refute this suggestion. T/I A
5. Birds are the only group of dinosaurs that survived the mass extinction of 65 million years ago. Speculate on how their ability to fly and endothermy (being warm-blooded) may have been keys to their survival. T/I A
6. Both salamanders and dogs have long tails, while bears do not. However, both bears and dogs have hair, while salamanders do not. Explain why having a long tail *is not* evidence that dogs are more closely related to salamanders than they are to bears Explain why having hair *is* good evidence that dogs and bears are more closely related than dogs and salamanders. K/U T/I A
7. Many scientists consider the term "missing link" to be m sleading. They suggest that it gives a false impression that evidence should have been found. Instead, they counter that newly discovered evidence simply adds to our understanding—and that it was never "missing." Do you th nk the term "missing link" is mislead ng? Why or why not? A
8. Use the cladogram in **Figure 12** to answer the following questions. Assume that each number represents the evolution of a new feature and that each letter represents a species alive today. K/U T/I

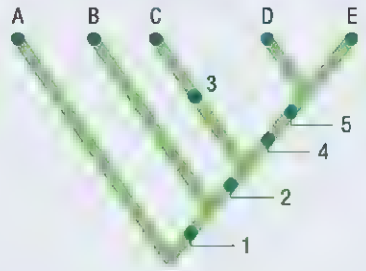

Figure 12

   (a) Construct a table of derived traits, using the relationships shown in Figure 10.
   (b) Which two species are most closely related?
   (c) List the synapomorphies shared by Species C and E.
   (d) To which species is Species C most closely related?
   (e) Is Species B more closely related to Species A or E? Explain your reasoning.
   (f) Do any numbers represent new features that were not needed to draw this cladogram? Which?
9. Examine the fossil hind limbs in **Figure 13**. Scientists believe this animal was a transitional species between land mammals and modern whales. Do you think this animal spent all, some, or none of its time on land? Explain your answer. T/I

Figure 13

GO TO NELSON SCIENCE

8.6 — *Biology* JOURNAL —

Tiktaalik—Triumph of a Theory

ABSTRACT

Among the most significant events in evolution was the invasion of the land by terrestrial vertebrates. Paleontologist Neil Shubin used the theory of evolution to correctly predict the location of fossil remains of a transitional species in Canada's High Arctic. The species, *Tiktaalik roseae*, has many features of both fish and four-limbed land vertebrates. Shubin and his colleagues published their dramatic findings in the prestigious journal *Nature*.

Introduction

Fossils of the now famous *Tiktaalik roseae* were first discovered on Ellesmere Island in the Canadian Arctic in 2004 (**Figure 1**). *Tiktaalik* has an odd mix of features. It has fins and scales, a neck and wrist bones, and an unusual flattened head. As a result it was nicknamed "fishapod." The discovery not only produced a very important transitional fossil, but also served as a perfect example of how scientists use and test theories.

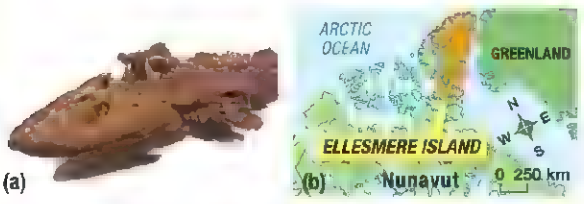

Figure 1 (a) Fossils of *Tiktaalik* were discovered (b) within 1000 km of the North Pole on Ellesmere Island in the Canadian Arctic.

The Power to Predict

Neil Shubin is a palaeontologist and professor at the University of Chicago. He is keenly interested in major evolutionary steps, including the evolution of the first land vertebrates. According to the theory of evolution, the first land vertebrates evolved from fish that made the transition onto land. Therefore, the theory predicts that in the past there must have been species that were transitional between lobe-finned fish and the first simple land vertebrates. Lobe-finned fish have bones extending part way into their fins and were therefore considered the most likely ancestors of the first animals to walk on all fours on land. When he began his search in the 1990s, Shubin knew that no transitional fossil species between land vertebrates and lobe-finned fish had been found. He hoped that by using the theory of evolution he could predict where to find such fossils.

Shubin began his research by gathering information on all the fossil finds of both primitive land vertebrates and lobe-finned fish. He noted several key points:

- The first fossils of lobe-finned fish appeared 390 million years ago.
- The earliest fossils of land vertebrates appeared 360 million years ago.
- The earliest land vertebrate fossils were found in freshwater sedimentary deposits.
- Fossils of lobe-finned fish were also associated with freshwater sedimentary deposits.

Shubin used these facts to make three inferences:

1. The transition from sea to land occurred some time between 390 million and 360 million years ago (**Figure 2**).
2. The transition occurred in freshwater ecosystems.
3. Fossils of transitional species would be found in freshwater sedimentary deposits from about 375 million years ago.

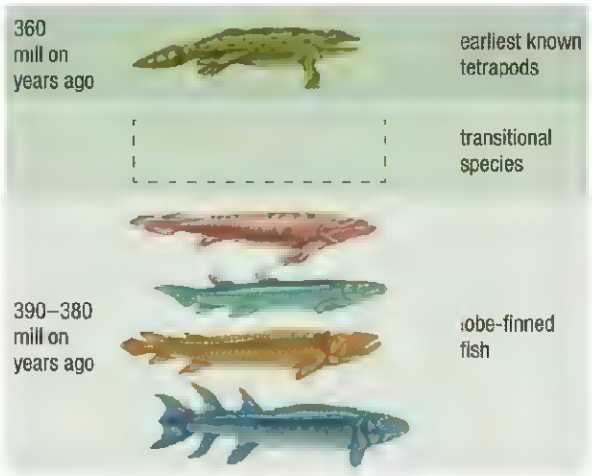

Figure 2 Theory predicted that transitional species would have lived between 390 million and 360 million years ago.

Shubin now knew what he was looking for and set out to find it in the map room of the local library. There, Shubin examined geological maps of the world looking for sedimentary rocks that had been deposited in freshwater and were approximately 375 million years old. They also had to be at Earth's surface. Rocks buried a half kilometre underground would be inaccessible. Of the three suitable deposits in North America that Shubin found, only one had not been explored in the past.

Field Work Begins

In 1999, Shubin and his team organized their first expedition to Ellesmere Island. At first their explorations were unsuccessful. Their first year's dig site turned out to be of marine deposits from an ancient ocean. In 2000, they moved their exploration site to the east and began again. That year they unearthed a rich fossil deposit containing many freshwater fish species. In the following years they returned to the same site to keep digging. In 2004, they unearthed *Tiktaalik* and knew immediately that their predictions had been confirmed.

The "Fishapod"

The 10 fossil specimens that Shubin and his team found are extremely well preserved. They range in size from just under 1 m in length to almost 3 m. *Tiktaalik* really does look like a cross between a fish and a four-legged land animal. Like fish, *Tiktaalik* had webbed fins supported with thin bones, gills, and scales. However, like four-limbed vertebrates, *Tiktaalik* had a neck and shoulders, thick ribs, and sturdy wrist bones (**Figure 3**). The skull of *Tiktaalik* was flattened, with eyes on top and two notches that are closer in size to those of land vertebrates than of fish. In early land vertebrates the notches function as primitive ears.

Tiktaalik was not able to walk, but its limb bones would have allowed it to prop itself up in a "push-up" position. Based on the overall shape of its head and body, *Tiktaalik* likely lived in shallow fresh water.

Scientific Recognition

Shubin and his fellow researchers knew that their findings were of great scientific significance. They reported their initial findings in two scientific papers that they submitted to the prestigious journal *Nature* in October 2005. After peer review, the articles were accepted for publication in February 2006 and published in April of that year. The *Tiktaalik* discovery was the cover story.

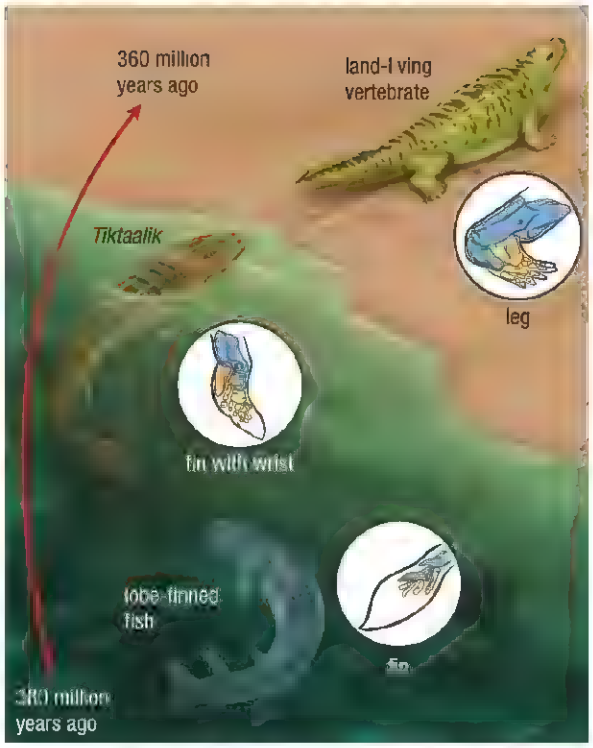

Figure 3 *Tiktaalik* had features of both fish and land vertebrates.

Further Reading

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GO TO NELSON SCIENCE

8.6 Questions

1. How did an understanding of the theory of evolution enable Shubin to predict the age and type of sedimentary rock in which he would find *Tiktaalik*? K/U
2. Why did Shubin look for fossils in Canada's north? K/U
3. It took five years of field work to find *Tiktaalik*. What does this suggest about the nature of palaeontology? What challenges do you think Shubin's team faced? A
4. Some fish have primitive lungs. Do you think *Tiktaalik* had lungs in addition to gills? Why or why not? Use the Internet and other sources to check your prediction. A
5. Articles submitted to the science journal *Nature* undergo a rigorous peer review process before being accepted. What is the benefit of such a process? Why would scientists not publish their findings in journals that do not require a review? T/I A

GO TO NELSON SCIENCE

8.7 Human Evolution

Like every other species, humans have evolved a combination of characteristics that enabled them to survive and flourish. In this section we examine what characteristics are responsible for human success and how and when humans evolved.

Figure 1 Even young children can manipulate objects.

primate a group of relatively large-brained, mostly arboreal mammals that includes prosimians, monkeys, apes, and humans

Human Biological Characteristics

What makes humans unique as a species? Human success can be attributed in large part to our ability to perform complex reasoning, coupled with an exceptional ability to learn, to make and use sophisticated tools, and to communicate using complex language. These human abilities also required the evolution of at least three distinct physical characteristics. We have a very large brain relative to body size, our hands are capable of fine manipulation and coordination (**Figure 1**), and we walk upright (bipedal), freeing our hands to use tools.

But dolphins have large brains, many animals can communicate, and apes and some birds make and use tools. What is different in humans is the degree to which these and other biological characteristics have evolved.

Human Phylogeny

Homo sapiens are primates. **Primates** are a relatively small group of mammals characterized by large brains relative to body size, forward-directed eyes, flexible hands and feet, and arms that can rotate fully. Many primates also have opposable thumbs that can touch their fingers and enable them to hold and manipulate objects. Most primates have tails (**Figure 2**).

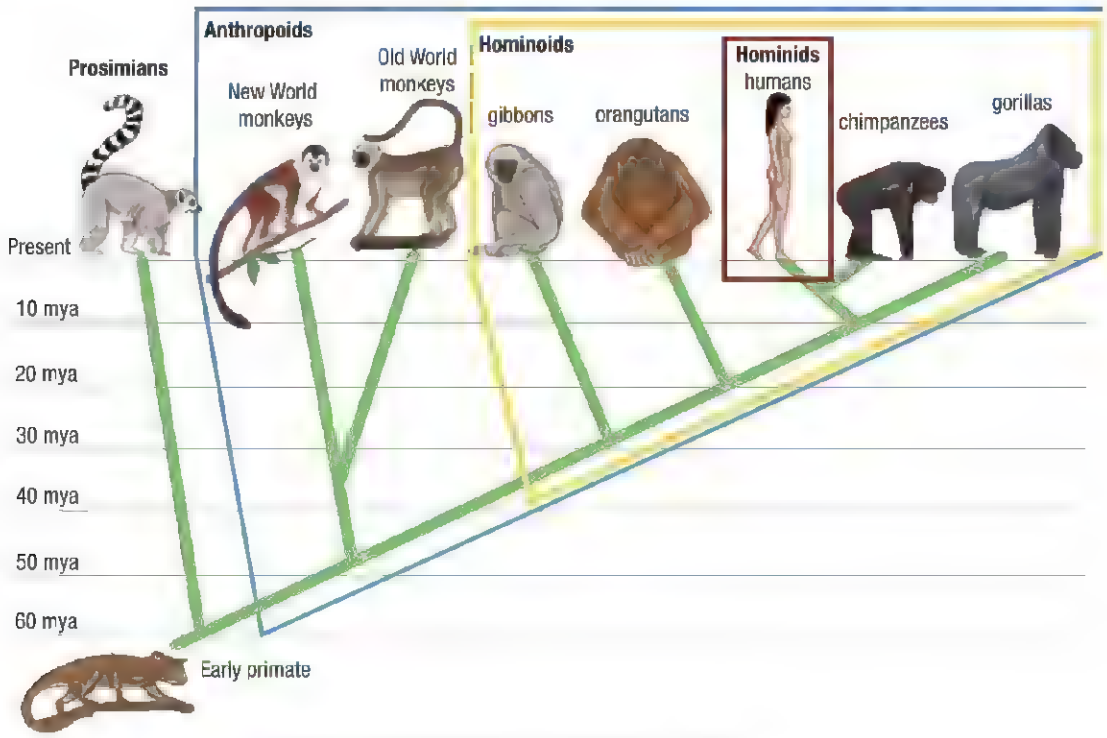

Figure 2 Cladogram showing the phylogeny of primates

prosimian the group of primates that includes lemurs, lorises, and tarsiers

anthropoid the group of primates that includes monkeys, apes, and humans

All primates share a common ancestor dating from about 60 million to 70 million years ago. The evolutionary tree branches early on, giving rise to the **prosimians**, relatively small nocturnal species, and the anthropoids. The **anthropoid** group then splits into two distinct groups: the monkeys and the hominoids, or apes. During this

time, continental drift was separating South America (the New World) from the land mass that would form Africa and Eurasia (the Old World). With the split, the early ancestors of monkeys divided into New World and Old World populations. The apes, easily distinguished by their lack of a tail, branched into the lesser apes, the gibbons, and what are referred to as the great apes and humans.

Genetic sequences of the entire human and chimpanzee genomes have now been completed. Detailed analysis of the genomes confirms that chimpanzees are our closest living relatives. Humans and chimpanzees share approximately 98.8 % of their DNA. Humans and chimpanzees both differ from gorillas by about 1.6 %. The most recent common ancestor we share with chimpanzees lived in Africa more than 6 million years ago. The branch ending with modern humans is a clade of many different species, including our direct ancestors. Members of this clade are called **hominids**.

Investigation 8.7.1

Human and Chimpanzee Chromosome Comparison (page 368)
In this observational study you will have a chance to compare and analyze human and chimpanzee chromosomes.

hominid all species descended from the most recent common ancestor of chimpanzees and humans that are on the human side of the lineage

The Hominid Fossil Record

Hominid fossils record information about the sequence of steps in the evolution of humans. Fossils of hip bones, feet, leg bones, and footsteps provide information about whether or not a species walked upright. Fossils of the skull can be measured and used to track trends in brain size (**Figure 3**). Remains of stone tools and burial sites inform scientist about tool use and early human culture.

Figure 3 Fossil skulls of (a) *Australopithecus africanus*, (b) *Homo habilis*, and (c) *Homo neanderthalensis* show a progression in brain size. Note that bipedalism evolved in Australopithecus before the subsequent evolution of large brains.

Between 6 million and 7 million years ago, *Sahelanthropus* was beginning to occasionally walk upright (**Figure 4(a)**, next page). Recently discovered fossils, and the first evidence of stone tools used by *Australopithecus afarensis*, date to 3.4 million years ago. By 2 million years ago, the first members of our own genus, *Homo gautengensis*, and *Homo habilis* had evolved. *Homo habilis*, often called the handy man, was making stone axes and large cutting tools. Tools for hunting permitted hominids to dramatically increase the amount of meat in their diet, providing a rich source of protein and fats. By this time, hominid brains were significantly larger than the chimpanzee-sized brains of australopithecines.

The use of hearths for cooking dates to at least 790 000 years ago, and fire may have been used for cooking as early as 1.5 million years ago. Cooking food may have reduced disease and increased the variety of foods that could be consumed. Perhaps most notably, hominid brain size increased relatively rapidly from about 800 000 years ago to 200 000 years ago. During that time, *Homo heidelbergensis* evolved and may have given rise to both *Homo neanderthalensis* and *Homo sapiens*. The first modern humans had evolved by about 100 000 years ago in East Africa. **Figure 4(b)** (next page) illustrates a simplified version of a widely accepted but tentative cladogram of the *Homo* genus.

Today the hominid fossil record of more than 20 species consists of fossils ranging in size from small bone fragments to almost complete skeletons. They include the spectacular *Australopithecus afarensis* fossil finds at Laetoli, Tanzania, which include a set of 69 footprints dated to 3.6 million years ago. These footprints show that human ancestors evolved the ability to walk upright long before they had large brains (**Figure 5**, next page). Although the precise relationships among the many early hominid species remain unclear, an early branch probably gave rise to a number of robust *Paranthropus* species with heavy jaws and relatively small brains, while another ultimately gave rise to the genus *Homo*.

LEARNING TIP

Becoming Human
Hominid evolution happened gradually over millions of years. Over time, an *Australopithecus* species changed enough to be considered the first *Homo* species. Although the process is continuous, scientists must still decide on a specific point to switch naming from one genus to another. This is analogous to becoming an adult. Even though the process is gradual, you gain adult status "instantly" on your eighteenth birthday.

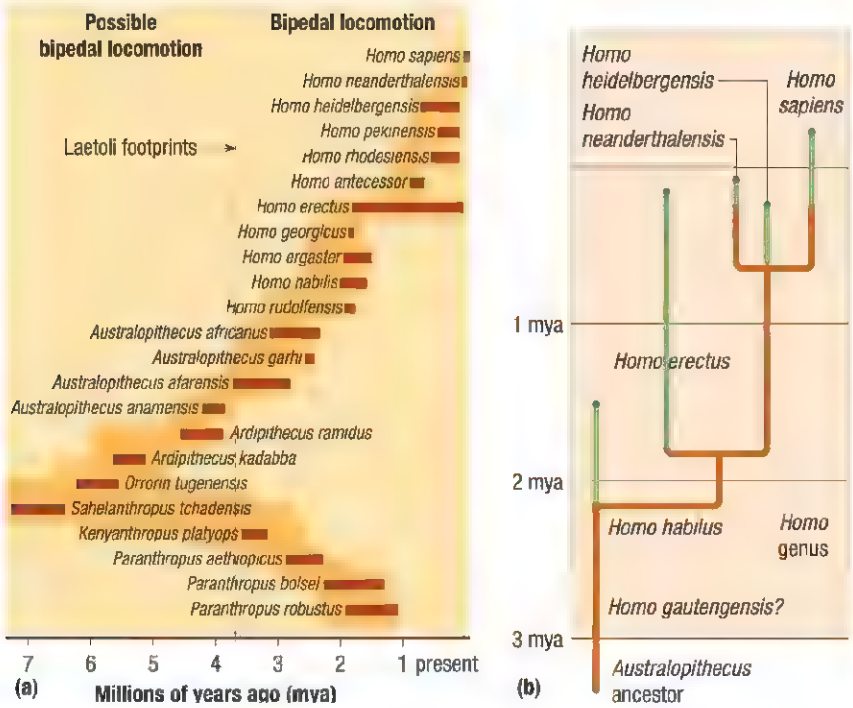

Figure 4 (a) Time frames during which early hominid species were living. Two very recently discovered hominid species, *Homo gautengensis* and *Australopithecus sediba*, are not included in this chart. (b) This simplified cladogram depicts the probable relationships within the *Homo* genus. Fossil evidence of the new species *Homo gautengensis* suggests it may have been an ancestor of *Homo habilis*.

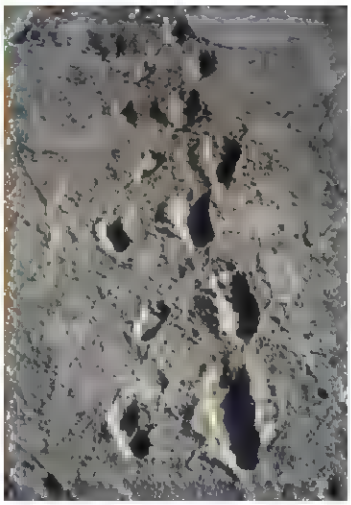

Figure 5 The Laetoli footprint fossils are clear evidence of upright walking dating to about 3.6 million years ago.

Mini Investigation

Following Footsteps in Time

Skills: Researching, Predicting, Planning, Performing, Observing, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1

In 1976, anthropologist Mary Leakey's team discovered a set of 69 hominid tracks in Laetoli, Tanzania. The 3.6-million-year-old fossils are the earliest evidence of bipedal motion in a hominid ancestor. In this investigation you will do a correlational study to predict the height of the individuals who made the Laetoli footprints.

Materials and Equipment: measuring tape

1. Make predictions about possible correlations between foot length, stride length, and height.
2. Measure the height and right foot length of at least 10 people. Ideally choose individuals with a wide range in height.
3. Have each individual walk at a normal leisurely pace; measure the distance they travel in 10 steps. Use this value to calculate their average stride length.
4. Plot two graphs—one of height versus foot length and one of height versus stride length. Draw a line of best fit through both sets of data.
5. Use the Internet and other sources to research the Laetoli and human footprints.

A. Did you find a correlation between foot length and/or stride length and height? Describe the correlation(s). T/I

B. Use your graphs to estimate the height of the two individuals in **Table 1**. T/I A

Table 1 Laetoli Footprint Data

Characteristic	Individual 1	Individual 2
foot length	18.5 cm	21.5 cm
stride length	28.7 cm	47.2 cm

C. Ask your teacher for the heights of the two individuals as calculated by paleontologists. How close were your height estimates to those of paleontologists? Suggest possible reasons for any differences. T/I

D. What role did volcanic eruptions and rainfall play in the formation of the fossilized tracks? T/I

E. Describe the comical events surrounding the discovery of the Laetoli fossils. T/I

F. How do the Laetoli and human footprints differ from those of chimpanzees when they walk on two feet? A

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Out of Africa

Fossils record the history of the distribution of species in both time and space. Fossil evidence tells the story of when and where our ancestors evolved and how they spread out across and around the world.

All early hominids evolved and lived in Africa (**Figure 6**). The first species to spread beyond Africa was *Homo erectus*, about 1.9 million years ago. The *H. erectus* population that left Africa spread out across much of Eurasia and survived until at least 100 000 years ago. The next species to spread beyond Africa, some 500 000 to 300 000 years ago, were the ancestors of the Neanderthals. *Homo neanderthalensis* populated parts of Europe. Relatively soon after the earliest modern humans evolved, they too began to spread out of Africa and into Europe and Asia, eventually reaching the Americas.

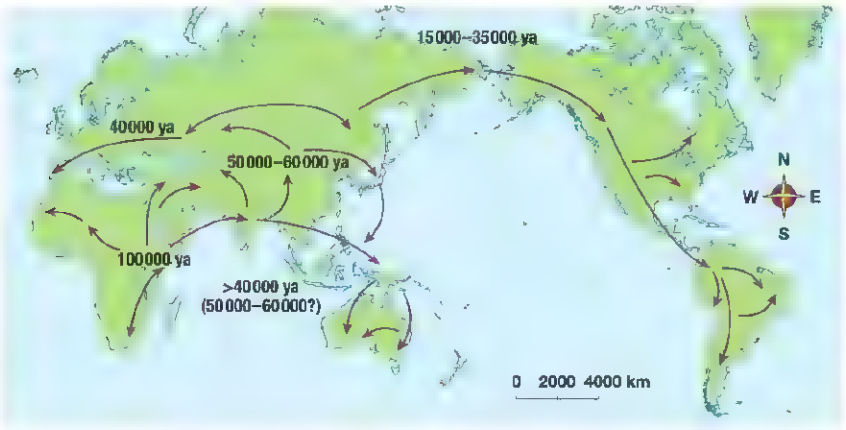

Figure 6 Migration routes of early hominids

Fossils and DNA

In what can only be described as a stunning technological achievement, scientists have been able to extract enough DNA from Neanderthal bones to sequence the entire Neanderthal genome. This has allowed geneticists to compare the DNA of Neanderthals with that of modern humans. The most striking discovery is that some small sequences of the Neanderthal genome are found in humans of Asian and European descent. These genetic remnants no longer have any function in humans, but they do suggest that some interbreeding may have occurred when early *Homo sapiens* made contact with Neanderthals.

Cultural Evolution

The first biologists to compare human and chimpanzee DNA were so struck by their similarity that they joked that perhaps the only differences between humans and chimpanzees were cultural. Their joke was not without some grain of truth. While our genetic differences are less than 2 %, our cultural differences are enormous.

Like humans, chimpanzees engage in some ritualized behaviours and use symbolic gestures to communicate (**Figure 7**). They also have a complex social organization. However, neither the chimpanzee nor any other animal has developed anything comparable to the extraordinary richness of human culture. More than 6000 human languages have been spoken, and human societies have engaged in countless artistic endeavours in music, dance, and the fine arts. Humans admire and cherish the talents of others. We have athletic heroes and movie stars. Human societies have different rituals, customs, and belief systems.

It is fascinating to consider how biological evolution might have influenced the development of culture and vice versa. Evidence suggests that from the time of our common ancestor with the chimpanzee, our ancestors lived as hunter–gatherers for more than 300 000 generations. In only the last 1000 generations or less have humans domesticated

CAREER LINK

Anthropologist
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WEB LINK

To learn more about the migration patterns of *Homo* species,

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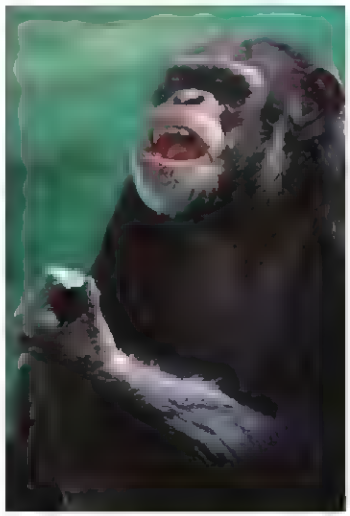

Figure 7 Chimpanzees use both facial expressions and simple hand gestures to communicate.

plants and animals, developed agricultural systems, and begun to live in large population centres. Only during the last 10 generations has our population size skyrocketed.

There is evidence in the fossil record that our own species, *Homo sapiens*, and *Homo neanderthalensis* both performed burials and made body ornaments more than 50 000 years ago (**Figure 8**). While some believe that both species evolved these behaviours independently, others suggest that the Neanderthals began copying the activities of humans shortly after the two species came in contact.

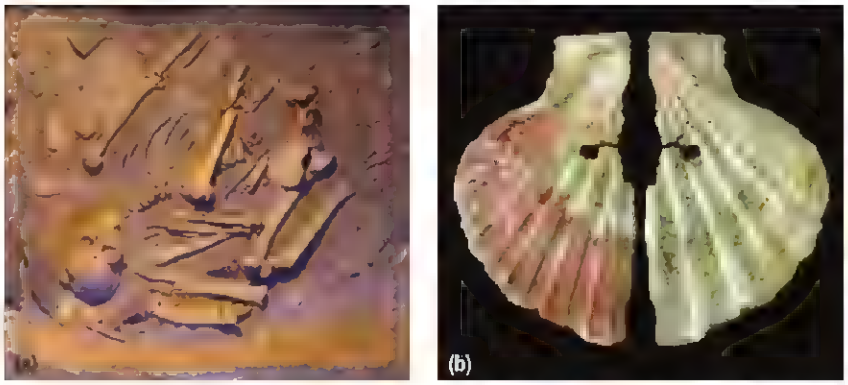

Figure 8 (a) Neanderthals performed burial rituals. (b) Perforated shells made into a neck pendant along with pigments that might have been used as cosmetics—from a Neanderthal site

UNIT TASK BOOKMARK

As you work on your Unit Task, consider how changes in our culture influence the evolution of other species.

A vital component of human culture is language and communication. Without the development of a rich spoken language, humans could not have realized our current success as a species. Evolutionary biologists are just beginning to understand the evolution of speech. We now know, for example, that a gene called FoxP2 codes for a protein that regulates a number of other genes and is vital for human speech. Individuals with even one defective copy of the gene have a severe speech and language disorder. The gene is found in all mammals and is highly conserved—meaning it varies little from species to species. The human and Neanderthal version of the FoxP2 gene differs from that of the chimpanzee in just two bases out of more than 2100. Genetic analysis also provides evidence that these two mutations have been strongly favoured by natural selection. It could be that one or both of these mutations provided our early ancestors with an enhanced ability to communicate.

Cultural Evolution Influences Biological Evolution

An interesting example of how cultural evolution influences biological evolution is evident in the recent evolution of lactose tolerance. Lactose tolerance evolved as human populations began to domesticate goats, cattle, and camels, and consume their milk. In these populations natural selection favoured those rare individuals who were more capable of digesting lactose. Mathematical modelling suggests that tolerant individuals had a 4 % to 10 % enhanced reproductive success in these populations. In this way, it was the cultural choice to domesticate livestock and consume their milk that created the new selective pressure for the evolution of lactose tolerance (**Figure 9**). In fact, the very rapid changes in human culture over the past 10 000 years have actually sped up human evolution. Researchers examining the human genome have uncovered evidence to suggest that the rate of human evolution has been greater over the past several thousand years than during the past few million years.

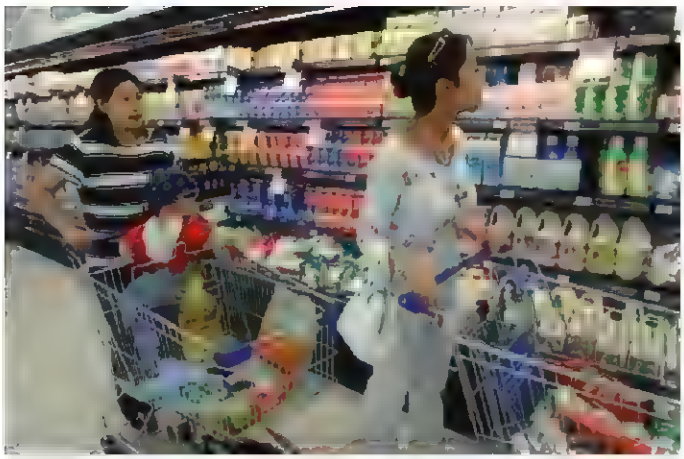

Figure 9 Lactose tolerance is a recently evolved trait.

Human culture has influenced the evolution of many other species but none more so than domesticated species. Indeed, the domestication of plants and animals by artificial selection and breeding is nothing less than directed evolution by humans. It is interesting to consider that after 300000 generations of our own biological evolution, the human population numbered no more than a few million. It has been our ability to direct the evolution of other species that has allowed us to mass-produce foods and feed our own population that now numbers in the billions (**Figure 10**).

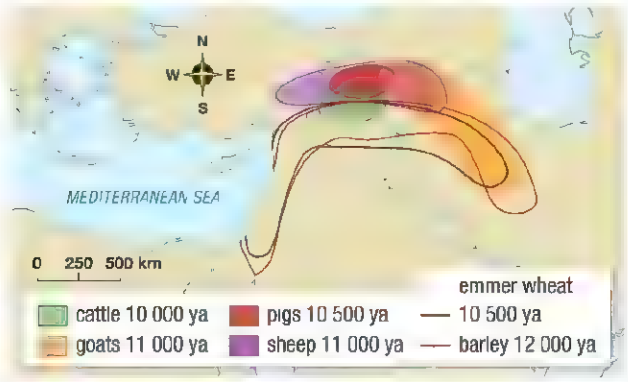

Figure 10 Humans have directly influenced the evolution of many species, including species we have domesticated through artificial se ection. "ya" means years ago.

Human Races

Detailed comparisons of human populations from around the world have conclusively shown that, from a biological perspective, human "races" do not exist. Traits that we associate with races, most notably skin colour, are visually obvious but genetically minimal. There is far more diversity *within* so-called races than there is *between* races. The classification of humans by race is therefore a cultural choice on a par with classifying people based the language they speak, their blood type, or their religious beliefs (**Figure 11**).

Figure 11 Although humans have used skin colour as a way of categorizing people into races, the underlying genetic differences are very slight and there are no biologically distinct races of humans.

Are Humans Still Evolving?

Is our evolutionary path of any consequence today? Does it matter if we evolved from a common ancestor of apes? Are we still evolving today? Understanding our evolutionary past and how evolutionary processes work today has many benefits. For example, it can provide insights into healthcare problems. We know that in our past, rich food sources were scarce and natural selection favoured individuals who could detect sweet-tasting and fatty foods and could gain weight during times when food was readily available. Our sense of taste evolved to "let us know" that these were valuable foods. In our modern world, we still relish these foods but now it is easy for us to overindulge (**Figure 12**). This evolutionary preference for ice cream and similar foods is therefore partly responsible for the problems of obesity and heart disease.

Darwinian medicine, the use of evolutionary theory to understand medicine, is providing many important insights into the cause and spread of diseases. An evolutionary perspective can be very important. For example, humans often get a fever with a serious infection. The first question an evolutionary biologist might ask is whether or not a fever is an evolved response of the body to help fight off the infection. If this is the case, then taking a drug to lower your body temperature might be unwise. Similarly, is coughing an evolved mechanism to expel disease-causing organisms from your lungs? If so, would taking a medication that suppresses a cough be helpful?

In modern society, vitamin D deficiency is widespread. This is not at all surprising from an evolutionary perspective. For millions of years, ancestral and modern humans spent time outdoors every day and evolved the ability to synthesize vitamin D when exposed to sunlight. Today many people spend little or no time outside, and

Figure 12 Throughout much of our evolutionary past, natural selection favoured a fondness for rich foods.

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Epidemiologist
Epidemiology is a branch of medicine that deals with the distribution and control of diseases. To learn about becoming an epidemiologist,

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when they do they are told to use sunscreen. Researchers are investigating the best way to balance the need to protect ourselves from damaging UV radiation and the risk of skin cancer with our evolved requirement to synthesize vitamin D.

In serious infectious diseases, biologists can track the evolution of the disease-causing agents as well as human evolutionary responses to these diseases. For example, a newly discovered allele called CCR5-D32 provides very strong protection against HIV/AIDS infections and may be under the influence of strong selective pressure in some populations.

Research This

Evolution on the Track

Skills: Researching, Analyzing

SKILLS HANDBOOK A2.1, A5.1.

Evolutionary biology is providing insights on the running track. Humans evolved as barefoot walkers and runners. Although humans are not fast compared to most other mammals, evidence suggests that humans did evolve to be efficient at running long distances. Barefoot running is rare in modern society. Instead, most of us wear specially designed sports shoes for running or other athletic activities. In this activity you will investigate the advantages and disadvantages of barefoot running.

1. Research the differences in how shoed runners and barefoot runners land on their feet as they run.
2. Investigate the current trend in barefoot running and the claim by Daniel Lieberman, a professor of human evolutionary biology at Harvard University, that it is possible to run barefoot on the hardest of surfaces.

A. Which running method produces more impact stress on the runner? T/I

B. How might natural selection have influenced the running mechanics of humans? Would you expect our natural running style to cause undue stress on our bodies? T/I A

C. Is it possible to just switch from running with shoes to running barefoot? Explain. A

D. Describe the key advantages and disadvantages of running barefoot. T/I

E. Abebe Bikila and Zola Budd were both champion athletes. In what events did they compete? K/U

F. Would you ever consider routine barefoot running? (**Figure 13**) Why or why not? A

Figure 13 Have you considered running in bare feet?

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CAREER LINK

Behavioural Psychologist
Behavioural psychologists study human behaviour. To learn more about becoming a behavioural psychologist,

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A Human Legacy?

Evolution can inform us about where we have come from but not where we are going. We have evolved a brain and body capable of great achievements in the arts and in understanding the world around us. We have discovered our own biological origins and have the tools and freedom to direct our own future. Yet humans also behave in ways that threaten our own future and the future of other species.

There is no doubt that humans are biologically limited by our evolutionary history. We are not going to sprout wings and fly, but there is nothing in our genes that prevents us from making intelligent choices about our own future. We have certainly made much progress—legalized slavery and routine sacrifice were once widespread, accepted practices. Today, in most countries women and men have equal rights under the law, and forced child labour has been criminalized. We have evolved a brain capable of knowing which actions are needed to ensure a secure and sustainable future for ourselves and our descendants as well as for the biodiversity of life on Earth as a whole. How human society will decide to act in the future remains an unknown.

8.7 Summary

- Key evolutionary characteristics of humans include bipedalism, large brain size, and hands capable of fine manipulation.
- Chimpanzees are our most closely related living species.
- There is a rich fossil record of human ancestors consisting of more than 20 hominid species.
- *Homo sapiens* first evolved in Africa and began spreading out from Africa about 50 000 years ago.
- Biological and cultural evolution influence each other.
- An understanding of human evolution has many applications.

8.7 Questions

1. What selective advantage does each of the following traits provide to humans? K/U
   (a) a large brain
   (b) upright walking
   (c) complex finger movements
   (d) complex language
2. Most ground-dwelling mammals have eyes that look to the side, giving them a wide field of view to help them avoid predators. Many tree-dwelling mammals have eyes that are directed forward, giving them better 3-D vision. Suggest an evolutionary explanation for why ground-dwelling humans have forward-directed eyes. K/U
3. Look at your feet. What feature of the arrangement of your toes provides evidence of an evolutionary history that involved a tree-dwelling lifestyle? T/I A
4. What evidence suggests that human ancestors walked upright before they evolved large brains? T/I A
5. Humans have an innate ability to learn new behaviours. In contrast, most behaviours of most species are instinctive. This suggests that there are advantages and disadvantages of learned behaviour. For each of the following, decide how the learned behaviour is advantageous and/or disadvantageous: K/U
   (a) Young humans learn to walk at about one year old, while deer fawns walk when they are a few hours old.
   (b) Young humans learn their parents' language, while most frogs and birds sing their mating calls instinctively.
   (c) Humans learn to adapt to many different environmental conditions, while most species use instinctive behaviours suited to a specific type of environment.
6. In 2003, scientists discovered the fossil remains of a 1 m tall hominid with a small brain. They called the species *Homo floresiensis*, and it is affectionately known as "the hobbit." Use the Internet and other sources to learn more about this discovery. T/I
   (a) Are all scientists convinced these fossils represent a new species?
   (b) What alternative hypotheses have been presented to explain the small brain size of the individual?
   (c) What is the current status of *Homo floresiensis*? Which hypothesis is more widely accepted?
7. Compare modern humans and Neanderthals. What evidence suggests we are very closely related species? K/U K/U
8. Explain why biologists do not use characteristics such as skin colour or spoken language to classify humans. T/I A
9. Humans have lived as small groups of hunter–gatherers during most of the last 100 000 years. Our food consisted of some animals and many plants. Sweet foods, fatty foods, and salts were relatively rare. Today the favourite foods of most people fit into these same categories. T/I A
   (a) Make a list of 10 of your favourite foods. How many of them are sweet, high in fat, or salty?
   (b) Suggest a way that natural selection might have caused us to evolve love for these foods.
   (c) How has the evolutionary love of these foods influenced societal problems related to obesity and poor eating habits?
10. It is thought that the initial population of *Homo sapiens* that left Africa was relatively small, while the population that remained in Africa was quite large. Use this information to predict whether genetic variability will be higher among human populations in Africa or in other parts of the world. Use the Internet to check your prediction. T/I K/U
11. *Homo sapiens* have existed for only a few hundred thousand years. Most of the recent success of humans can be attributed to cultural and technological advances. T/I A
    (a) Do you think humans will continue to evolve as a species? Support your ideas.
    (b) What selective pressures do you think humans may be experiencing now and may experience in the future?
    (c) Hypothesize about potential human adaptations that could result.

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CHAPTER 8 Investigations

Investigation 8.1.1 CORRELATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Bird Monogamy and Sexual Dimorphism

Bird species exhibit a variety of lifelong mating patterns. Some are monogamous and mate for life, while others are polygamous—choosing a different mate, or multiple mates, each year. Bird species also vary in the appearances of males compared to females. Some bird species exhibit sexual dimorphism, with noticeable differences between males and females. In other species the sexes are similar. In most dimorphic species the males are the more brightly coloured sex. This characteristic helps males attract females but makes them more vulnerable to predators. In this investigation you will explore possible correlations between these variables.

Purpose

To look for correlations between lifelong mating patterns and the occurrence of sexual dimorphism

Variables

In this correlational study the variables you will consider are (1) mating pattern of the species and (2) appearance of the sexes.

For this investigation, mating patterns should be classified as either *monogamous* or *polygamous* and the appearance of the sexes as either *similar* or *dimorphic*.

Note that in a correlational study, scientists look for relationships between variables but do not control or manipulate any variables. Therefore, the variables are not classified as independent and dependent. Keep in mind that correlations may be positive or negative. In a positive correlation the presence of, or increase in, one variable is associated with an increased likelihood of the presence of, or increase in, another variable. In a negative correlation the presence of, or increase in, one variable is associated with the absence of, or decrease in, another variable.

Procedure

1. Use the Internet and other sources to compile data for a variety of bird species. Your data are unlikely to result in equal numbers of monogamous and polygamous species, but you should try to include at least 10 species of each. The larger the number of bird species you consider, the better.
2. Plot your data as histograms using a format similar to that shown in **Figure 1**. The pairs of columns should represent numbers of species that are dimorphic and have similar-looking sexes.

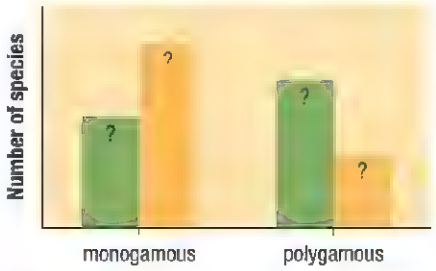


Figure 1

Analyze and Evaluate

(a) Were there any correlations between the variables? If so, describe the correlation(s). K/U

(b) Were monogamous species more or less likely to be dimorphic than polygamous species? K/U

(c) Were dimorphic species more or less likely to be polygamous or monogamous? K/U

(d) Use your understanding of the theory of evolution to offer a possible explanation for any correlations you found. What do these results suggest about the different selective pressures at work in bird species? T/I

(e) How might the benefit of one trait have influenced the selective advantage of another? T/I

Apply and Extend

(f) Male red-capped manikins are brightly coloured and perform a complex "moon-walk" mating dance, while male and female penguins look very similar. Predict whether or not these species are monogamous or polygamous. Use the Internet and other sources to test your predictions. T/I A

(g) Besides birds, few land vertebrate species have evolved bright coloration of males. Suggest a possible explanation for this difference between birds and most other vertebrates. T/I A

(h) Male and female ruffed grouse look similar, except during courtship when the males raise their neck feathers and fan out their tails to create a visual display (**Figure 2**). These grouse spend much of their time on the ground. How might natural selection have favoured this particular adaptation? A

Figure 2 Male ruffed grouse in courtship display

(i) The males of many, but by no means all, bird species are known for their complex and often beautiful songs. These songs are usually associated with courtship or territorial displays. Use your understanding of evolution to predict whether the following statements are true or false. Explain your prediction. Consider doing online research to find out. T/I A

I) Well-known songbirds are more likely to be polygamous than monogamous.

II) Polygamous species that have similar-looking sexes will not use songs to attract mates.

GO TO NELSON SCIENCE

Investigation 8.5.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Looking for SINEs of Evolution

Whales have undergone very large physical changes in their recent evolutionary past. This makes comparisons with other mammals difficult. It also makes understanding their evolutionary kinships particularly challenging. However, genetic sequences are now providing biologists with powerful new tools for revealing evolutionary relationships. One potentially ideal type of genetic sequence is known as a SINE (short interspersed element). In this investigation you will use the presence of SINEs to construct a cladogram and infer the evolutionary relationship of whales to some land mammals.

Purpose

To use the presence of SINEs to investigate the evolutionary kinship of whales with cows, giraffes, hippopotamuses, and pigs

Predictions

Make the following two predictions:

- Which of these species do you suspect whales are most closely related to?
- Which of these species to you think whales are least closely related to?

Procedure

Background: SINEs are sequences of DNA (more than 100 bases long) that have become inserted into a chromosome at random during a viral infection. Because the DNA molecules in chromosomes contain millions of bases, the chances of two identical SINEs getting inserted into the same location in many different individuals is extremely remote. If all *African* elephants, for example, have the same SINE at the same position on chromosome #9, we can conclude that all African elephants inherited this SINE from a common ancestor. By extension, if every *Asian* elephant also has the identical SINE in the same position on their chromosome #9, then we can assume that the SINE was found in an individual that was an ancestor to both Asian and African elephants.

1. Use the information in **Table 1** to construct a cladogram showing the phylogenetic relationships between these five species. **Note:** Each of these SINEs can be considered a recently derived trait.

Table 1

Species	SINEs			
	A	B	C	D
cow	+	+	−	+
pig	−	−	−	+
fin whale	−	+	+	+
giraffe	+	+	−	+
hippopotamus	−	+	+	+
camel*	−	−	−	−

*The camel is the outgroup.

2. Your cladogram should include the letters A, B, C, and D at positions indicating when each of these SINE insertion events may have taken place.
3. Also include the label MRCA to indicate the position of the *most recent common ancestor* of whales and their most closely related species.

Analyze and Evaluate

(a) Were your predictions correct? To which species are whales most closely related? To which species (ignoring the outgroup) are they most distantly related? K/U

(b) Which SINE insertion occurred first—A or B? Explain your reasoning. K/U

(c) Are pigs more closely related to camels or whales? How do you know? K/U

(d) What SINE(s) would you expect to find in all giraffes? What SINE(s) would you never expect to find in giraffes? K/U

Apply and Extend

(e) Imagine a geneticist discovers a new matching SINE in DNA samples from a hippopotamus and a cow. Predict the results of looking for this same SINE in DNA samples from each of the other mammals. T/I

(f) A new SINE is discovered in the pygmy hippopotamus but not in the closely related common hippopotamus. Do you think it would be possible to find this same SINE in whales? Explain your reasoning. T/I

(g) Imagine you are describing the results of this investigation to a fellow student. You explain that, when tested, a number of hippopotamuses, whales, cattle, and giraffes all had the same SINE insertion B in matching positions in their chromosomes. The other student suggests that this is not evidence of evolution, but simply evidence that these animals had each been infected by the same virus. Is this a strong alternative hypothesis? Why or why not? T/I A

Investigation 8.7.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Human and Chimpanzee Chromosome Comparison

Chimpanzees are thought to be the mostly closely related living species to humans. Biologists believe our most recent common ancestor lived between 5 million and 7 million years ago. Genetic information provides compelling evidence for this close kinship.

Humans have 22 sets of autosomal chromosomes and 2 sex chromosomes, while chimpanzees have 23 sets of autosomal chromosomes and 2 sex chromosomes. In this investigation you will compare the banding patterns in human and chimpanzee chromosomes, looking for evidence of a shared ancestry. You will also examine detailed DNA evidence to account for a significant difference between the genomes of these species.

Purpose

To compare human and chimpanzee chromosomes, looking for evidence of shared ancestry

Equipment and Materials

- complete set of chimpanzee karyograms
- complete set of human karyograms
- scissors and glue stick
- telomere worksheet
- human chromosome 2 DNA sequence (partial)
- highlighter

Procedure

Part A: Comparing Banding Patterns

Background: Geneticists use specialized stains to reveal distinctive and detailed banding patterns within chromosomes. The sizes and locations of the bands are carefully measured and displayed in diagrams called karyograms (**Figure 1**). These banding patterns are variable and can be used to compare species. All members of the same species share virtually identical chromosome banding patterns. Very closely related species have similar banding patterns, while species that are not closely related have no matching patterns.

Figure 1 Karyograms show detailed banding patterns.

1. Obtain the handouts of the human and chimpanzee karyograms from your teacher. Use a pair of scissors to cut out the chimpanzee chromosomes.
2. Take each chimpanzee chromosome and find its human homologue—the human chromosome that most closely matches the banding pattern.
3. Align and glue each chimpanzee chromosome next to its human homologue.

4. Note that human chromosome #5 and its chimpanzee homologue have, on either side of the centromere, a matching but reversed banding pattern (**Figure 2**). These matching but "flipped" patterns are evidence of past inversion events. Carefully examine each human/chimpanzee pair. Attempt to locate the eight additional cases of chromosome inversions. Highlight the portions that represent inverted segments.

Figure 2 These chromosomes had identical banding patterns, but an inversion event has flipped a portion of one of the chromosomes (top chimpanzee, bottom human).

Part B: Evidence of a Fusion Event

Background: Chimpanzees have an extra pair of autosomal chromosomes. As you may have discovered, two small chimpanzee chromosomes are homologous with the single large human chromosome #2. If humans and chimpanzees share a recent common ancestor, then some event must have caused this difference. Because gorillas and orangutans also have 23 sets of autosomal chromosomes, we can assume that the change took place in the human lineage. The most likely explanation is that a fusion event took place in which two smaller chromosomes became attached "end to end" to form the larger chromosome #2. If this did occur, it would explain the matching banding patterns.

We can test this hypothesis by a more detailed analysis of human chromosome #2. The ends of chromosomes have special DNA regions called telomeres. Telomeres are sections of repetitive DNA base sequences that serve a number of functions. In all primates the repetitive DNA sequences are recognizable and usually found nowhere else. If two telomeres joined, we would expect to find these recognizable sequences at the location of a fusion site.

5. Obtain the telomere worksheet and the copy of the partial DNA sequence from human chromosome #2.
6. Read through the telomere worksheet and identify the short DNA base repeat sequence that you would expect to find at an end-to-end (telomere-to-telomere) fusion site.
7. Search for this repeat sequence within the human DNA sequence. Record the beginning and ending positions of telomere sequences within chromosome #2.

Analyze and Evaluate

(a) Were the banding patterns more or less similar than you expected? What does the similarity suggest about the kinship of humans and chimpanzees? T/I

(b) Compare the human and chimpanzee chromosome banding patterns. Estimate the percent similarity between the two species. Consider inversions as "matches," as long as the same banding patterns occur within the inverted segments. T/I

(c) Assume that chimpanzees and humans share a recent common ancestor that lived 7 million years ago. If each inversion represents a single mutation event, calculate the average number of years between these mutation events. Would you describe this mutation rate as rapid or slow? T/I

(d) One function of telomeres is to protect the ends of the chromosomes in a way that is analogous to the front and back covers of a book. Use this analogy to describe the kind of evidence one would expect to find if two books became joined together by a fusion event. T/I A

Apply and Extend

(e) When two chromosomes fuse, the new chromosome will have a second centromere. Over time one of these centromeres becomes non-functional. Label the location where you would predict to find this non-functional centromere on human chromosome #2—assuming it resulted from a fusion event. T/I

(f) Geneticists are able to recognize non-functional centromeres by their DNA sequence. Use the Internet and other sources to find out if such a sequence has been located in human chromosome #2. T/I

(g) Use the Internet and other sources to find out if it is possible for individuals who have fused chromosomes to breed successfully with individuals who have separate chromosomes. Report on your findings. A

(h) Inversions are mutations in which entire portions of a chromosome are flipped end for end. This is analogous to taking a number of pages out of an instruction manual—which represents the chromosome—flipping them over, and reinserting them. The "genes" in this case would be analogous to sentences written on the pages. A

(i) If someone handed you the manual, would you still be able to read all or most of the sentences?

(ii) Which sentences might be "damaged" by the inversion?

(iii) If the manual pages were mostly blank—representing non-coding DNA—would the inversion be more or less likely to cause damage to the instructions?

GO TO NELSON SCIENCE

CHAPTER 8 SUMMARY

Summary Questions

1. Create a study guide based on the Key Concepts listed at the beginning of the chapter, on page 324. For each point, create three or four subpoints that provide further information, relevant examples, explanatory diagrams, or general equations.
2. Return to the Starting Points questions at the beginning of the chapter, on page 324. Answer these questions using what you have learned in this chapter. Compare your answers with those that you gave at the beginning of the chapter. How has your understanding changed? What new knowledge and skills do you have?

Vocabulary

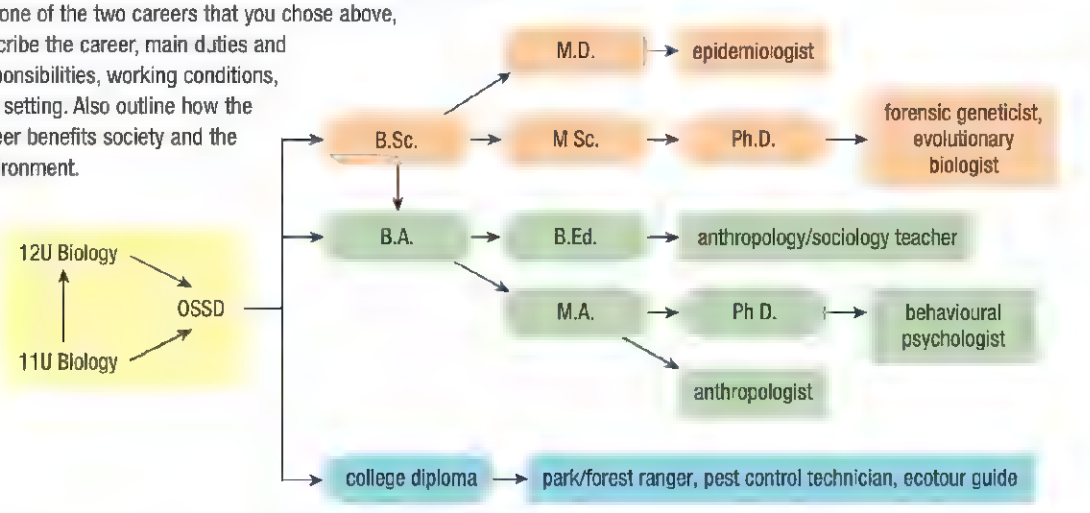
directional selection (p. 326)
stabilizing selection (p. 327)
disruptive selection (p. 328)
sexual selection (p. 328)
genetic drift (p. 331)
genetic bottleneck (p 332)
founder effect (p. 332)
Hardy–Weinberg principle (p. 333)
microevolution (p. 336)
speciation (p. 336)
reproductive solating mechanism (p. 336)
prezygotic mechanism (p. 336)
postzygotic mechanism (p. 336)
allopatric speciation (p. 337)
sympatric speciation (p. 339)
adaptive radiation (p. 341)
divergent evolution (p. 342)
convergent evolution (p. 343)
coevolution (p. 344)
macroevolution (p. 348)
abiogenesis (p. 348)
Cambrian explosion (p. 350)
cladistics (p. 350)
derived trait (p. 350)
synapomorphy (p. 350)
theory of gradualism (p. 353)
theory of punctuated equilibrium (p. 353)
transitional form (p. 354)
primate (p. 358)
prosimian (p. 358)
anthropoid (p. 358)
hominid (p. 359)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or postgraduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select two careers related to evolution that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



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CHAPTER 8 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Types of natural selection include
   (a) directional selection
   (b) stabilizing selection
   (c) disruptive selection
   (d) all of the above (8.1) K/U
2. Sexual selection in a species may result in which of the following? (8.1) K/U
   (a) female territorial competitions
   (b) larger males than females
   (c) longer-lived, weaker males
   (d) identical males and females
3. The driving force of evolution is
   (a) the action of natural selection upon beneficial mutations
   (b) consequences of human influence
   (c) climate change
   (d) genetic drift (8.1) K/U
4. The evolution of a new species is called
   (a) reproductive isolation
   (b) genetic drift
   (c) microevolution
   (d) speciation (8.2) K/U
5. Patterns of evolution include which of the following? (8.3) K/U
   (a) adaptive radiation
   (b) divergent evolution
   (c) convergent evolution
   (d) all of the above
6. The Cambrian explosion was
   (a) Earth's first mass extinction event
   (b) a period of rapid evolution and species diversification
   (c) the beginning of life on Earth
   (d) the reason for the extinction of the dinosaurs (8.5) K/U
7. Humans are
   (a) primates
   (b) anthropoids
   (c) hominids
   (d) all of the above (8.7) K/U
8. All early hominids evolved in and lived in
   (a) Eurasia
   (b) Africa
   (c) North America
   (d) Mesopotamia (8.7) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

9. Evolution occurs when natural selection acts upon the genetic variation in an individual. (8.1) K/U
10. Artificial selection is the favouring of any trait that specifically enhances the mating success of an individual. (8.1) K/U
11. Not all evolutionary changes are the result of natural selection. (8.1) K/U
12. Hardy and Weinberg used mathematical reasoning to explain that in large populations where only chance is at work, allele frequencies tend to stay constant. (8.1) K/U
13. Prezygotic mechanisms and postzygotic mechanisms prevent different species from interbreeding while living in the same area. (8.2) K/U
14. Sympatric speciation may occur after members of an original species become geographically isolated from each other. (8.2) K/U
15. A species undergoes coevolution when its evolutionary success is closely linked with that of another species. (8.3) K/U
16. Human activities are causing an increase in the rate of extinctions. (8.4) K/U
17. Synapomorphy is a method of determining evolutionary relationships based on recently evolved traits. (8.5) K/U
18. The theory of punctuated equilibrium states that as new species evolve, they appear similar to the original species and only gradually become more distinctive. (8.5) K/U
19. *Archaeopteryx*, *Aetiocetus*, and *Tiktaalik roseae* are considered transitional species. (8.5, 8.6) K/U

To do an online self-quiz,
GO TO NELSON SCIENCE

CHAPTER 8 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. Which type of selection favours individuals with variations at opposite extremes of a trait over individuals with intermediate variations? (8.1) K/U
   (a) directional selection
   (b) stabilizing selection
   (c) disruptive selection
   (d) sexual selection
2. The founder effect occurs when
   (a) a population experiences genetic drift
   (b) a small number of individuals establish a new population
   (c) allele frequencies remain constant
   (d) all of the above (8.1) K/U
3. New species may form after an original species separates into two geographically isolated populations. What is this called? (8.2) K/U
   (a) prezygotic speciation
   (b) postzygotic speciation
   (c) sympatric speciation
   (d) allopatric speciation
4. The relatively rapid evolution of a single species into a number of distinct but closely related species filling a variety of formerly empty ecological niches is known as
   (a) adaptive radiation
   (b) divergent evolution
   (c) convergent evolution
   (d) coevolution (8.3) K/U
5. Which of the following is the best example of the theory of gradualism? (8.5) K/U A
   (a) a species of snake that adapts back and forth to the changing climate of its ecosystem
   (b) an ancient sea creature's slow evolution into a tetrapod (meaning "having four limbs") that lives primarily on land
   (c) a cheetah that must develop the ability to run faster in order to catch its prey
   (d) a dinosaur species that slowly dies out as fewer and fewer offspring are created
6. Abiogenesis is the origin of life from
   (a) a different species
   (b) a different ecosystem
   (c) non-living matter
   (d) plant matter (8.5) K/U
7. Based on the fossil evidence found in recent years, which of the following is true of *Tiktaalik*? (8.6) K/U
   (a) It has wings and a beak.
   (b) It has fins and scales.
   (c) It has a small, perfectly round head.
   (d) all of the above
8. Which of the following is among the three distinct physical characteristics that make it possible for humans to make and use sophisticated tools? (8.7) K/U
   (a) a very large brain relative to body size
   (b) upright walking (bipedalism)
   (c) hands capable of fine manipulation and coordination
   (d) all of the above

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

9. Directional selection is very common in artificial breeding, where individuals with an enhanced trait are often selected. (8.1) K/U
10. Selective pressures can result only from abiotic factors. (8.1) K/U
11. Microevolution can sometimes lead to speciation. (8.2) K/U
12. Adaptive radiation has a negative impact on biodiversity. (8.3) K/U
13. The strongest evidence for the cause of the mass extinction of the dinosaurs is an extended period of global warming some 65 million years ago. (8.5) K/U
14. *Tiktaalik* really does look like a cross between a fish and a four-legged land animal. (8.6) K/U
15. *Homo sapiens* are primates. (8.7)
16. Evolutionary biologists have long understood the evolution of speech. (8.7) K/U

Write a short answer to each question.

17. The process of natural selection does *not* occur by chance. Explain why. (8.1) K/U
18. What are the two most common forms of sexual selection? (8.1) K/U
19. What does the theory of evolution say with regard to babies born at weights offering the best chance of surviving birth? (8.1) K/U
20. Explain what a reproductive isolating mechanism is. (8.2) K/U
21. What role does polyploidy play in evolution? (8.2) K/U

22. Does divergent evolution increase or decrease competition? Explain your answer. (8.3) K/U
23. Why is coevolution compared to an evolutionary arms race? (8.3) K/U
24. When does adaptive radiation occur? (8.3) K/U
25. What is the asteroid that formed a crater located on the edge of the Yucatan peninsula thought to be responsible for? (8.5) K/U
26. What does the "Cambrian explosion" refer to? (8.5) K/U
27. What is a fossil in "transitional form"? (8.6) K/U
28. What is *Tiktaalik*, and why is it significant? (8.6) K/U
29. Name one biological characteristic that makes humans unique as a species. (8.7) K/U
30. Into what two groups does the anthropoid group split? (8.7) K/U

Understanding

31. Selective pressures may result from any number of abiotic or biotic factors. Choose two different abiotic or biotic factors and discuss how each can result in different patterns of natural selection. (8.1) K/U
32. It is often easy to speculate about the selective pressures that have been at work over hundreds of generations and thousands of years. For each trait, describe the selective pressures that might have given rise to it. (8.1) K/U A
    (a) the giraffe's long neck
    (b) the cheetah's amazing speed
    (c) the snake's unlocking jaw
33. Explain why genetic bottlenecks can result in both the evolution of species and the extinction of species (8.1) K/U
34. Not all evolutionary changes are the result of natural selection. What is one way for an evolutionary change to occur without being the result of natural selection? Give an example of such a change. (8.1) K/U T/I
35. Changes that occur within species are sometimes relatively easy to understand. Natural selection favours certain characteristics in each species. (8 2) T/I A
    (a) What factors lead to speciation?
    (b) Describe how an entirely new species might evolve.
36. The separation of a single population into two isolated populations can lead to speciation, but it can also threaten the survival of a species. Describe how humans influence speciation, giving a specific example. (8.2) K/U A
37. There are various forms of speciation. Describe allopatric speciation and give an example of this type of speciation giving rise to a new species. (8.2) K/U
38. Natural selection has favoured the evolution of a wide variety of herbivores. Northern Ontario forests are home to many rodents, the largest taxon of herbivorous mammals. (8.3) T/I
    (a) Describe how the varied species of rodents that occupy Northern Ontario's forests are a prime example of divergent evolution.
    (b) Distinguish between two or three of these different rodent species.
39. Though any type of evolution involves the change in a species over time, convergent evolution is very different from divergent evolution. (8.3) K/U T/I
    (a) Describe what is meant by the term "convergent evolution."
    (b) Explain why dolphins and sharks are a good example of convergent evolution.
40. New things evolve, and living things go extinct. The rates at which these changes take place vary. Human activities, however, have increased the rate of extinction. (8.4) K/U T/I
    (a) What happened in the seventeenth century to the dodo bird?
    (b) Explain how an increase in species diversity was actually to blame.
    (c) What roles did humans play in this, and was it avoidable?
41. (a) Describe what is meant by the term "mass extinction."
    (b) What instances have there been of such a phenomenon over time?
    (c) What can cause or what has caused a mass extinction? (8.5) K/U T/I
42. Explain how the evolutionary processes and products surrounding the Cambrian explosion support the theory of punctuated equilibrium. (8.5) K/U T/I
43. Phylogenies are based on a careful evaluation of a wide range of evidence, including the fossil record, morphology, and genetics. How are cladistics used in applying this evidence? (8.5) K/U
44. Biologists are able to apply the science of cladistics to large numbers of related organisms and determine their phylogenetic relationships, based on synapomorphies. (8.5) K/U T/I
    (a) What is a synapomorphy?
    (b) Give an example of a synapomorphy that you know exists between two species.

45. According to the theory of evolution, the first land vertebrates evolved from fish that had made the transition onto land. Therefore, the theory predicts that in the past there must have been species that were transitional between lobe-finned fish and the first simple land vertebrates (**Figure 1**). (8.6) T/I A
    (a) What is the significance of the species pictured below?
    (b) Explain how the features you see are an important part of the overall significance of this species to evolution.

Figure 1

46. By two million years ago, the first members of our own species, *Homo gautengensis* and *Homo habilis*, had evolved. *Homo habilis*, often called the handy man, made stone axes and large cutting tools. What is the significance of the ability of *Homo habilis* to make and use simple tools? (8.7) K/U T/I

47. Primates are a relatively small group of mammals characterized by large brains relative to body size, forward-directed eyes, flexible hands and feet, and arms that can rotate fully. All primates share a common ancestor dating from about 60 to 70 million years ago. (8.7) K/U
    (a) What are the two main groups of primates?
    (b) Distinguish between these two groups. What characteristics make them different?

48. Anthropologist Mary Leakey and her team discovered hominid footprints in Tanzania in 1978. What was the significance of these 3.6-million-year-old fossils? (8.7) K/U

49. Though it is clear that biological evolution has influenced human cultural evolution, it is also thought that our cultural evolution has influenced our biological evolution. Explain how this can be. Give an example of a case in which you think our cultural evolution has influenced our biological evolution. (8.7) T/I A

Analysis and Application

50. Selective pressures may result from any number of abiotic or biotic factors and can result in different patterns of natural selection. Explain how the varied bill length of different hummingbird species is a good example of directional selection. (8.1) T/I A

51. Directional selection occurs when selection favours individuals with a more extreme variation of a trait. This is sometimes a result of nature, but humans can also bring about an increase or decrease in the value of a trait. Show how this can be done, and give an example of human-influenced directional selection. (8.1) T/I A

52. The most common forms of sexual selection are female mate choice and male-versus-male competition. Give an example of each, and hypothesize as to why in some species the female chooses her mate while in others she accepts whichever proves himself more dominant. (8.1) T/I A

53. For a new species to evolve, individuals from the original species must become reproductively isolated from the remainder of the population and they must establish a new interbreeding population. (8.2) K/U T/I A
    (a) What is a reproductive isolating mechanism?
    (b) Compare and contrast ecological isolation and mechanical isolation. How does each, in its own way, contribute to the formation of new species?
    (c) Give real-world examples of each type of isolation.

54. Sometimes, sympatric speciation is the direct result of human action. Such is the case with North America's hawthorn fly. How did human action affect the hawthorn fly of North America? Why is the case of the hawthorn fly a good example of sympatric speciation? (8.2) K/U A

55 Compare and contrast divergent evolution and convergent evolution. How are these two forms of evolution different from each other? Include a real-world example of each type of evolution in your answer. (8.3) T/I A

56. The African (Old World) lappet-faced vulture and Canadian (New World) turkey vulture are both scavenging birds that feed on carrion (**Figure 2**). Both species are large birds with hooked beaks, unfeathered heads, and sharp claws. Old World vultures are related to hawks and eagles, whereas New World vultures are thought to be related to storks. (8.3) K/U A
    (a) What type of evolution is this an example of? Explain why.
    (b) How might these characteristics have evolved?

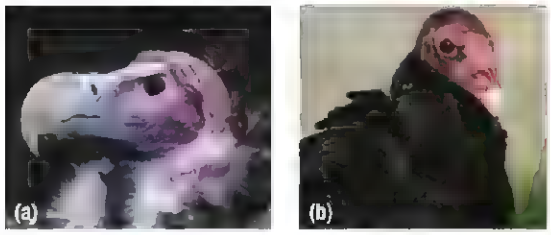

Figure 2 (a) Lappet-faced vulture and (b) turkey vulture

57. Hypothesize as to what set of circumstances might lead up to coevolution. Describe one example of coevolution between a plant and an animal, and describe how the link between them was established, as well as how one or the other or both continue to evolve, if they do. (8.3) T/I C A

58. A number of human activities are causing the rapid acceleration in the rate of species extinction. These activities pose a serious threat to the biodiversity of life on Earth and the sustainability of natural resources. (8.4) T/I A
    (a) Choose one human activity that you know has resulted in or may some day result in a single species or multiple species extinctions.
    (b) Hypothesize as to how the human action or actions you discussed can be altered or reversed to pose less of a threat to other species.

59. At one time, dinosaurs dominated Earth's terrestrial ecosystems. These reptiles, some of which were enormous, first evolved some 250 million years ago. Using knowledge from this chapter, hypothesize as to why dinosaurs, in some cases, were such enormous creatures. What evolutionary pressures or selections might have made such size important, or beneficial, or necessary? (8.5) K/U T/I

60. Suppose you are an anthropologist who has been hired by a team of other researchers to find an alternate theory for the cause of the extinction of the dinosaurs. Knowing what you now know about the reasons behind some extinctions in different ecosystems and environments, propose a new theory that plausibly explains the mass extinction of these incredible ancient creatures. Be creative, but use facts from your readings. (8.5) T/I C A

61. *Tiktaalik* was an important evolutionary discovery. Knowing what you know about *Tiktaalik*, explain how connections might be made (as they are frequently) in evolutionary pathways without the benefit of a *Tiktaalik* for supporting evidence. (8.6) K/U T/I

62. Genetic differences between humans and chimpanzees are less than 2 %. Knowing this, hypothesize as to why we are so different from chimpanzees. How can it be that we are more than 98 % genetically the same as chimpanzees? (8.7) K/U T/I A

63 **Figure 3** shows skulls of (a) *Australopithecus africanus*, (b) *Homo habilis*, and (c) *Homo neanderthalensis*.
    (a) Analyze the different skulls in determining how their variation was an essential part of the evolution experienced by hominid species
    (b) What did this variation ultimately mean for successive hominid species and, eventually, for humans? (8.7) T/I A

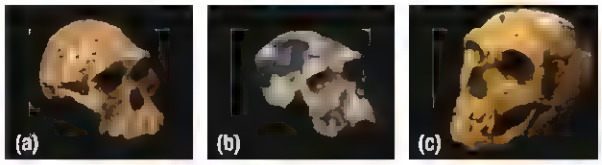

Figure 3

64. All primates share a common ancestor dating from about 60 million to 70 million years ago. From there, branches extend and divide, seeing the evolution of many different species and ultimately leading to human beings. Draw a phylogenetic tree that begins with the common ancestor to primates some 60 million to 70 million years ago and that branches out over the millions of years since. Be sure to include all of the species you learned about in your reading of Section 8.7. (8.7) K/U T/I

65. Fossils record the history of the distribution of species in both time and space. Fossil evidence tells the story of when and where our ancestors evolved and how they spread out across and around the world. (8.7) T/I A
    (a) Using your knowledge from Section 8.7, outline the various steps and stages that took place in the hominids' physical disbursement across the continents.
    (b) What type of speciation does such far-reaching migration represent, and what did that mean for the various hominid species?
66. Human evolution has influenced the evolution of many other species, but none more so than domesticated species. This human influence has even been referred to as "directed" evolution. (8.7) T/I C A
    (a) What is meant by "directed" evolution?
    (b) Give examples of human influence over a domesticated species that has altered the biological characteristics or genetic makeup of that species in some way. Cite specific examples.

Evaluation

67. (a) Analyze the Hardy Weinberg principle. How are scientists able to use mathematics to predict which populations are likely to exhibit the most evolutionary change?
    (b) What are the five conditions that scientists recognize will result in evolution? (8.1) T/I A
68 Humans interact with all other species. Our activities are responsible for everything from overfishing sea species and clear-cutting forests to actively supporting habitats and protecting many endangered species. Compare and contrast our varied roles in the evolution of other species. Choose a side and argue that we either do more damage or more good by our actions. Support your argument with facts. (8.1) T/I C A
69. For a new species to evolve, individuals from the original species must become reproductively isolated from the remainder of the population. Two mechanisms that prevent two populations from interbreeding when living in the same region are prezygotic mechanisms and postzygotic mechanisms. (8.2) K/U T/I A
    (a) Compare and contrast prezygotic mechanisms and postzygotic mechanisms.
    (b) Give one real-world example of each of these types of mechanisms, and explain how, in each case, the mechanism works.
70. Devise a fictitious ecosystem in which an animal species is directly influenced by a plant species to the point that the evolution of the animal species is altered. Structure the coevolutionary relationship such that the animal species is, over time, changed into a species that is unrecognizable compared to its original form. How did this occur? What role did the plant species play? (8.3) T/I C A
71. Pick any two species that you know to be closely related and argue that there is a "missing link" between them. Demonstrate by describing the two closely related species and showing that they are actually not so similar in characteristics, appearance, or biological makeup or structure. Support your argument with facts from your reading of this chapter. (8.5) K/U T/I A
72. Explain how human cultural evolution influences human biological evolution. Use specific knowledge from your reading of the chapter in your answer. (8.7) K/U T/I C

Reflect on Your Learning

73. Which of the different types of selection did you find the most interesting? Were you surprised to learn of the varied types of selection and of the different pressures they apply? Explain why. Did it surprise you to learn that not all evolutionary change is the result of natural selection? Why or why not? T/I A
74. Has anything you have learned about the different forms of speciation surprised you? Explain why or why not. What do you think about the human influences on speciation? T/I A
75. Knowing what you now know about the different ways by which species evolve, how has your view of the animal and plant life around you changed? In what ways do you now look at things differently? T/I A
76. Were you surprised to learn of the different periods of mass extinctions and intensified diversification in Earth's long history? Why or why not? T/I A
77. What do you think about what you read in the Biology Journal? Was it a surprise to you to learn that such species as *Tiktaalik* existed? What about this species did you find most fascinating? T/I A
78. After reading this chapter, how has your view of human evolution changed? T/I A

Research

GO TO NELSON SCIENCE

79. Research thoroughbred racehorses on the Internet (**Figure 4**). Look into how these amazing animals are an example of directional selection and how humans play a role in this selection. Find out as much as you can. Write a report on your findings. Present your report to your classmates. T/I C A

Figure 4

80. Research Charles Darwin and his theory of evolution on the Internet. Gather as much information as you can on this important scientist and his contributions to biology and other science disciplines. Write a report on your findings. Present your report to your classmates. T/I C A

81. Research cheetahs on the Internet. How did this species evolve? What type of evolution have cheetahs undergone, and what influences have led to their evolution? Write a report on your findings. Present your report to your classmates. T/I C A

82. Research the fish species found in lakes Victoria, Malawi, and Tanganyika in Africa. How are many of these species good examples of adaptive radiation? Why are many of these species unique to one or more of these lakes? Explore the similarities and differences among these fish species. Write a report on your findings. Present your report to your classmates.

83. Research the mass extinction of the dinosaurs on the Internet. What are some of the other theories offered to explain what happened 65 million years ago? Why is the asteroid theory the most widely accepted? Write a report on your findings. Present your report to your classmates. T/I C A

84. Research human evolution on the Internet. Based on your findings, make as complete a timeline as you can, showing the evolutionary path humans came down. Be sure to include dates and key fossil findings. Present your timeline to your classmates. T/I C A

85. You have seen how human languages have been used as an analogy for evolutionary processes. Now consider how evolution might influence "language" in other species. Many species of songbirds occur over a very wide geographic range. Would you expect songbirds of the same species that live very far apart to have the same calls or would you expect them to have evolved different regional "accents" or dialects? Do online research to learn more about bird songs and their geographic distribution. If the calls did vary, would this provide evidence for speciation? Report on your findings and explain your reasoning. T/I C

86. A recent scientific study indicates that genetic resistance to infectious diseases such as tuberculosis and leprosy is more common in populations with a long history of living in urban settings. Find out more about this study and how natural selection and living conditions in ancient cities can account for these genetic differences in modern human populations. A C

UNIT 3 UNIT TASK

Evolution for Everyone

Evolution is the unifying theory of all of the biological sciences. As such, scientists are able to apply their understanding of the theory to all topics or issues of interest in biology—from the treatment of patients in a hospital setting to the protection of fragile ecosystems in remote locations. Evolutionary biology provides a foundation for understanding the factors that underlie the forms, functions, and diversity of life. It also enables scientists to make predictions about how living things will respond to changes in their environment—changes ranging from a virus infection to global climate change.

In this Unit Task you will choose a current topic in applied evolutionary biology from medicine, conservation biology, agriculture, or a field of your choosing. You will complete an analysis of the application, reviewing the evolutionary principles at work, what the theory predicts, and how the theory is applied to the situation in question.

The Application

To begin this activity, you must first select a particular problem or issue of concern related to the life sciences. Because evolution is the unifying theory of biology, it can be applied to any topic associated with living things. Therefore you are free to choose from a wide range of topics that may interest you. You may choose to keep your issue broad or make it highly specific. Be sure to obtain teacher approval for your chosen topic before proceeding with further research.

Consider the following list of sample topics:

- How can a major environmental threat be understood and addressed (**Figure 1**)?

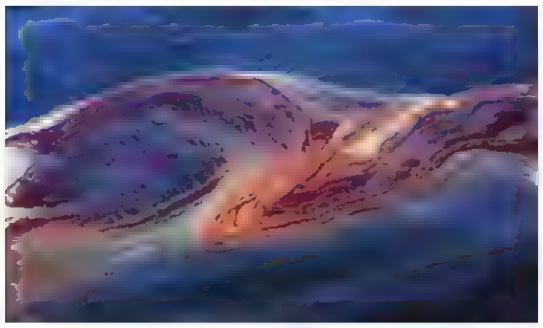

Figure 1 Oil leaking from the Deep Horizon oil rig into the Gulf of Mexico in 2010

- What impacts will climate change have on the diversity and distribution of species?
- How are changing lifestyles such as modern diets and daily routines altering our health in positive and negative ways (**Figure 2**)?

Figure 2 Our modern diet consists of foods with h gh amounts of fat and salt

- What are the possible benefits and consequences of genetically modified organisms? Are they a serious threat to our health and the environment, or are they the latest major scientific advance?
- How are human behaviours influenced by our evolutionary past? Should we be taking evolutionary biology into account in developing social policies?
- Habitat loss and overconsumption of wild species are serious global issues. How should we direct policy decisions in land-use planning and harvesting regulations?
- How can evolutionary biology be applied to our understanding of the spread and control of epidemic diseases?

Your Goal

To investigate the application of the science of evolutionary biology to a current problem or issue in the life sciences

Research

After choosing your issue of concern, conduct research to gain an understanding of the scope of the problem and the key factors involved. Investigate the key concepts and principles from evolutionary biology that relate to your issue. As you conduct this research, be sure to consider the ways in which an understanding of evolutionary biology can be and is being applied by scientists.

Consider the following questions:

- Is the genetic diversity of an individual species or the diversity of species overall an important factor? If so, how?
- How can understanding the evolutionary relationships between species provide useful information?
- How might natural selection play a role in this situation? How does the situation favour some individuals or some species over others?
- In what way is the environment changing? Is the change caused by humans? Is it intentional or unintentional? For example, climate change is an unintentional change in the environment on a grand scale, while a global vaccination campaign is an intentional change in the internal environment of the human body.
- How do these changes influence the selective pressures on the species of interest?
- What role does time play in the issue? Is there time for species to evolve? If so, would the expected evolutionary changes be beneficial or harmful?
- If the issue you are addressing is a problem, what solutions and strategies can help solve the problem? What role can and does evolution play in these potential solutions and strategies? Can evolution be advantageous or a barrier to finding effective and sustainable solutions?

Summarize

Based on your research findings and your own understanding of evolution, answer the following:

- How do scientists apply evolutionary biology to understand the nature of this issue or problem? In other words, how does evolution influence the issue or concern?
- How do scientists apply the theory of evolution to make predictions regarding this issue?
- How do scientists use evolutionary biology to make informed decisions and find solutions to the problem?

Communicate

Prepare a report in the form of a science journal article. Your report can be divided into the following components:

Abstract: a short paragraph summarizing the entire investigation

Introduction: a brief overview of the importance of diversity to the health of ecosystems

Findings: your research findings and analysis

Discussion: concluding remarks that summarize how evolutionary biology is applied to the chosen issue

Apply and Extend

1. Exchange your journal article with those of several of your fellow students. Read their reports and take note of their general findings.
   (a) Were other students able to find evidence of applications of the theory of evolution to modern-day issues in the life sciences? Elaborate.
   (b) Did they find evidence that evolutionary biology is an effective tool for making predictions? Provide examples to support your answer.
2. The theory of evolution has widespread applications in the biological sciences. How might a lack of understanding of evolution limit our ability to address important issues in life science?

GO TO NELSON SCIENCE

ASSESSMENT CHECKLIST

Your completed Unit Performance Task will be assessed using the following criteria:

Knowledge/Understanding

- ☑ your understanding of the role of genetic diversity in populations
- ☑ your understanding of the relationships between the environment and natural selection
- ☑ your understanding of the relationship between human-caused environment change and changes in selective pressures

Thinking/Investigation

- ☑ your ability to find and select relevant information
- ☑ your ability to synthesize information from a variety of sources
- ☑ your ability to evaluate the accuracy and currency of information from various sources
- ☑ your ability to recognize the application of evolution in understanding the issue and making predictions

Communication

- ☑ the organization and clarity of the information in your final report
- ☑ the effectiveness of your written presentation
- ☑ your use of appropriate visuals to support your findings and conclusions

Application

- ☑ your ability to recognize the application of evolution in understanding the issue and making predictions
- ☑ your recognition of the significance of evolutionary biology as the unifying scientific theory of the life sciences

UNIT 3 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Harmful mutations include those that cause
   (a) Huntington's disease
   (b) cystic fibrosis
   (c) reduced reproductive success
   (d) all of the above (7.1) K/U
2. From the perspective of a pest species, what type of mutation confers resistance to a pesticide? (7.1) K/U A
   (a) harmful mutation
   (b) neutral mutation
   (c) beneficial mutation
   (d) none of the above
3. Artificial selection requires which of the following? (7.1) K/U
   (a) hypothesis
   (b) independent variable
   (c) dependent variable
   (d) all of the above
4. Most fossils are in the form of
   (a) impressions in rock
   (b) impressions in soft clay
   (c) impressions in soft lake sediment
   (d) impressions in sand (7.2) K/U
5. Which of the following organisms is most likely to become a fossil over time? (7.2) K/U A
   (a) clam
   (b) jellyfish
   (c) land animal
   (d) land plant
6. Which of the following statements support(s) the assertion that fossils are remains of very ancient organisms? (7.2) K/U
   (a) There are many of fossils of organisms that no longer exist.
   (b) There are no fossils of most existing species.
   (c) Fossils are often buried deep within rock formations.
   (d) all of the above
7. Which of the following describes Charles Darwin's observations from the Galapagos Islands? (7.4) K/U A
   (a) no unique species
   (b) many native amphibians and land mammals
   (c) many species of plants, birds, insects, and some reptiles
   (d) all of the above
8. Biogeography is
   (a) the study of fossil organisms in order to learn about earlier forms of life
   (b) the observed geographic patterns of the distribution of species
   (c) the idea that global catastrophes have caused the widespread extinctions of species
   (d) the idea that Earth and all living things have been created in their present forms and are unchangeable (7.4) K/U
9. Which of the following pairs are homologous features? (7.4) K/U
   (a) horse hind leg and human arm
   (b) human arm and bat wing
   (c) mouse skull and giraffe skull
   (d) porpoise paddle and whale skull
10. Vestigial features include
    (a) the gills of a fish
    (b) the larynx of a giraffe
    (c) goose bumps on a wolf
    (d) the hip bones of a snake (7.4) K/U
11. A scientific theory such as evolution must be able to
    (a) explain observations
    (b) predict outcomes
    (c) be tested
    (d) all of the above (7.5) K/U
12. Since pseudogenes no longer serve a useful purpose in a species, they can be compared to
    (a) homologous features
    (b) analogous features
    (c) vestigial features
    (d) none of the above (7.6) K/U A
13. The increased oxygen-carrying capacity of the blood of native Tibetans is an example of
    (a) directional selection
    (b) stabilizing selection
    (c) disruptive selection
    (d) all of the above (8.1) K/U
14. According to Darwin's theory of natural selection, a struggle for survival is a result of which one of the following? (8.1) K/U
    (a) many species competing with one another
    (b) the large number of offspring born in each generation
    (c) the occurrence of mutations
    (d) the environment constantly changing

15. Which of the following is most likely to occur when a small number of individuals establish a new population? (8.1, 8.2) K/U
    (a) Hardy–Weinberg principle
    (b) genetic bottleneck
    (c) founder effect
    (d) mechanical isolation
16. Prezygotic mechanisms of reproductive isolation include
    (a) ecological isolation
    (b) hybrid infertility
    (c) zygotic mortality
    (d) none of the above (8.2) K/U
17. Convergent evolution is exhibited most clearly by which of the following animal pairs? (8.3) K/U A
    (a) whales and elephants
    (b) sharks and dolphins
    (c) flying squirrels and porcupines
    (d) lions and tigers
18. Throughout the history of life, the rate of speciation compared to the rate of extinction has generally been
    (a) greater
    (b) less
    (c) about the same
    (d) unrelated (8.4) K/U A
19. The study of abiogenesis is an effort to explain
    (a) why the dinosaurs became extinct
    (b) how life began
    (c) when life began
    (d) why the extinction rate is increasing (8.5) K/U
20. A cladogram shows
    (a) when groups of organisms arose
    (b) evolutionary relationships among groups
    (c) mass extinctions
    (d) gaps in the fossil record (8.5) K/U
21. Human success can be attributed to which of the following abilities? (8.7) K/U
    (a) complex reasoning and learning
    (b) complex tool making and use
    (c) communication through complex symbolic language
    (d) all of the above

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

22. Count Buffon, Carl Linnaeus, and Erasmus Darwin all proposed that life changed over time. (7.2) K/U
23. Cuvier's theory of catastrophism is consistent with Charles Darwin's theory of evolution. (7.2, 7.4, 7.5) K/U A
24. Charles Darwin finalized his theory of evolution during his voyage on the HMS *Beagle*. (7.3, 7.4, 7.5) K/U
25. The hypotheses that Charles Darwin proposed based on his observations of the Galapagos Islands have been supported by observations of life in the Hawaiian Islands. (7.4) K/U A
26. The eyes of flying insects and the wings of flying insects are analogous features. (7.4) K/U
27. Charles Darwin's reading of Malthus led him to wonder if the environment favoured certain individuals due to competition between species. (7.4) K/U A
28. Charles Darwin described natural selection as the way in which the environment favours the reproductive success of certain individuals. (7.5) K/U A
29. Darwin's theory of natural selection explained how and why species evolve. (7.6) K/U
30. The most common forms of sexual selection are female mate choice and male-versus-male competition. (8.1) K/U
31. Adaptive radiation is the evolution of a number of species each occupying different niches from an ancestral species. (8.3) K/U
32. Large-scale evolutionary changes are called endosymbiosis. (8.5) K/U
33. Derived traits are recently evolved traits. (8.5) K/U
34. Neither gradualism nor punctuated equilibrium play a significant role in evolutionary changes. (8.5) K/U
35. The discovery of *Tiktaalik* by Neil Shubin's team is a great success in the field of molecular biology. (8.6) K/U
36. Primate features include large brains compared to body size, side-facing eyes, flexible hands and feet, and arms that can rotate fully. (8.7) K/U
37. To date, the hominid fossil record has revealed two species. (8.7) K/U

UNIT 3 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. Artificial selection
   (a) reduces the genetic diversity of a population
   (b) increases the genetic diversity of a population
   (c) reduces the number of harmful mutations
   (d) rapidly produces new species (7.1) K/U
2. After his visit to the Galapagos Islands, Darwin concluded that all the species that lived in the Galapagos must have
   (a) crossed land bridges to the islands
   (b) arrived by air or water
   (c) no relation to animals on the mainland
   (d) none of the above (7.3) K/U
3. All vertebrate embryos have
   (a) gill slits
   (b) five finger bones
   (c) short forelimbs
   (d) none of the above (7.4) K/U
4. Which of the following four hammerhead sharks would be considered the most fit in terms of natural selection? (7.5) K/U
   (a) 10-year-old shark that has broken free from several fishing lines; no offspring
   (b) 15-year-old shark that has died from ingestion of trash in the ocean; five live offspring
   (c) 25-year-old shark; 15 offspring (all eaten while young)
   (d) 20-year-old shark with internal parasites; 10 live offspring
5. Selective pressures may result from
   (a) diseases
   (b) climatic conditions
   (c) food availability
   (d) all of the above (8.1) K/U
6. Biologists often describe evolution as a change in
   (a) the number of alleles in a population
   (b) the frequency of alleles in population
   (c) mutation rate
   (d) the immutability of nature (8.1) K/U
7. The many species of cichlid fishes in Africa present an excellent example of which pattern of evolution? (8.3) K/U
   (a) adaptive radiation
   (b) divergent evolution
   (c) convergent evolution
   (d) none of the above
8. In **Figure 1**, which species is the common ancestor for all groups except Species T ? (8.5) K/U
   (a) A
   (b) B
   (c) C
   (d) E

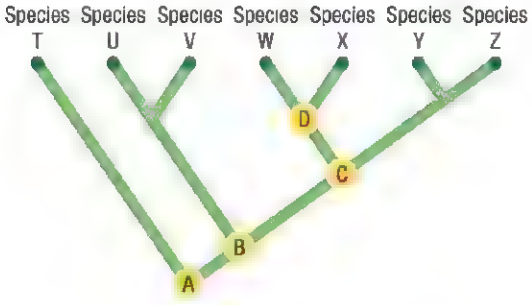

Figure 1

9. In Figure 1, which two species are most closely related? (8.5) K/U
   (a) U and V
   (b) U and T
   (c) X and Y
   (d) V and W

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

10. Most mutations are beneficial and give individuals a better chance of survival. (7.1) K/U
11. Neutral mutations do not play an important role in the evolution of a species. (7.1) K/U
12. Most species exhibit genetic variation. (7.1) K/U
13. In 1838, the Reverend Thomas Malthus claimed that the size of animal populations is limited by the availability of food. (7.2) K/U
14. To Chevalier de Lamarck, the excellent night vision of African bush babies would have been an example of the *use and disuse* principle. (7.2) K/U
15. The conditions required for fossil formation happen frequently. (7.2) K/U
16. Reverend Thomas Malthus believed that populations can continue to grow indefinitely. (7.4) K/U
17. On remote islands, animals are typically very scared of people. (7.4) K/U
18. The observation that "individuals within all populations vary" leads to the inference that some individuals will inherit characteristics that give them a better chance of surviving and reproducing. (7.5) K/U

19. A gamete that receives a chromosome with duplicated genes has a low chance of survival. (7.6) K/U
20. Often a small amount of interbreeding still occurs between populations that are gradually becoming reproductively isolated. (8.2) K/U
21. Convergent evolution can result in similar features evolving in very distantly related organisms. (8.3) K/U
22. A species is least likely to undergo adaptive radiation when there is very little competition for a variety of resources. (8.3) K/U
23. Coevolution is most pronounced in symbiotic relationships. (8.3) K/U
24. The fact that many species of fish and waterfowl are darker on top and lighter underneath is most likely a result of coevolution. (8.3) K/U
25. Over Earth's history, the rate of species formation has been, on average, less than the rate of extinction. (8.4) K/U
26. Eukaryotes have existed on Earth for at least 3.5 billion years. (8.5) K/U
27. For more than 100 million years, dinosaurs were the dominant vertebrate herbivores and carnivores on land. (8.5) K/U
28. A cataclysmic event is not needed to cause a species to go extinct. (8.5) K/U
29. Abiogenesis is the study of how life appears on island chains that were previously barren. (8.5) K/U
30. The hominid fossil record from 3.7 million years ago shows that our human ancestors evolved the ability to walk upright only after they had large brains. (8.7) K/U

Match the term on the left with the most appropriate description on the right.

31.

(a) beneficial mutations	(i) relatively rare but are favoured by natural selection
(b) harmful mutations	(ii) relatively low for individuals but can be numerous in populations overall
(c) duplication mutation	(iii) often neutral and so do not immediately benefit the individual
(d) mutation rates	(iv) are selected against and therefore have no influence on populations (7.6) K/U

32.

(a) directional selection	(i) occurs when the most common phenotype within a population is favoured by the environment
(b) stabilizing selection	(ii) favours individuals with a more extreme variation of a trait
(c) disruptive selection	(iii) favours reproductive success of individuals with certain traits over others
(d) sexual selection	(iv) favours individuals with variations at opposite extremes of a trait over individuals with intermediate variations (8.1) K/U

33.

(a) natural selection	(i) the gaining of new alleles from a different species
(b) small population size	(ii) introduces new alleles to a population
(c) mutation	(iii) increases the likelihood of genetic drift
(d) immigration or emigration	(iv) favours the passing on of some alleles over others
(e) horizontal gene transfer	(v) introduces or removes alleles in a population (8.1) K/U

34.

(a) behavioural isolation	(i) even very similar species may prefer occupying different habitats in a region
(b) temporal isolation	(ii) male gametes may not recognize and fertilize an egg of a different species
(c) ecological isolation	(iii) different species use different courtship and other mating clues to find and attract a mate
(d) mechanical isolation	(iv) different species breed at different times of the year
(e) gametic isolation	(v) differences in morphological features may make two species incompatible (8.2) K/U

35. (a) zygotic mortality (i) hybrid offspring remain healthy and viable but sterile
    (b) hybrid inviability (ii) a hybrid individual develops but either dies before birth or, if born alive, does not survive
    (c) hybrid infertility (iii) mating and fertilization are possible, but genetic differences result in a zygote that is unable to develop properly (8.2) K/U

36. (a) adaptive radiation (i) the large-scale evolution of a group into many different forms
    (b) divergent evolution (ii) the relatively rapid evolution of a single species into many new species, filling a variety of formerly empty ecological niches
    (c) convergent evolution (iii) the evolution of similar traits in distantly related species (8.3) K/U

Write a short answer to each question.

37. In science, what is the difference between a hypothesis and a scientific theory? (7.5) K/U
38. Why would unusually wide feet be defined as a beneficial adaptation for snowshoe hares? Give an example of an environment in which the hare's wide feet would have little to no benefit, and explain why. (7.1) K/U
39. Provide an example of the principle of "inheritance of acquired characteristics." (7.2) K/U
40. Explain why Darwin was surprised by the species he found in the Galapagos. (7.3) K/U
41. Provide a piece of evidence suggesting that moles and humans evolved from a common ancestor. (7.4) K/U
42. Define the term "adaptation" as it is used in the theory of evolution. (7.5) K/U
43. How do paleontologists use radioisotopes? (7.6) K/U
44. Define genetic bottlenecks and the founder effect. (8.1) K/U
45. Define genetic drift and provide a circumstance in which it occurs. (8.1) K/U
46. Provide one example of the consequences of human selective pressure and the matching evolutionary change and consequences. (8.1) K/U
47. Why does allopatric speciation prevent beneficial mutations arising in one population from being shared with another population? (8.2) K/U
48. Define sympatric speciation, and explain how human actions can result in sympatric speciation. (8.2) K/U
49. The Mountain bluebird lives at high elevations, while the Eastern bluebird prefers lower elevations. Which type of reproductive isolating mechanism is at work here? (8.2) K/U
50. Define macroevolution and list some of the large-scale processes associated with macroevolution. (8.5) K/U
51. Based on the fossils of ancestral whales such as *Pakicetus*, and a modern whale, how has the location of the whale's nostrils changed over time (**Figure 2**)? What selective advantage does the change provide? (8.5) K/U A

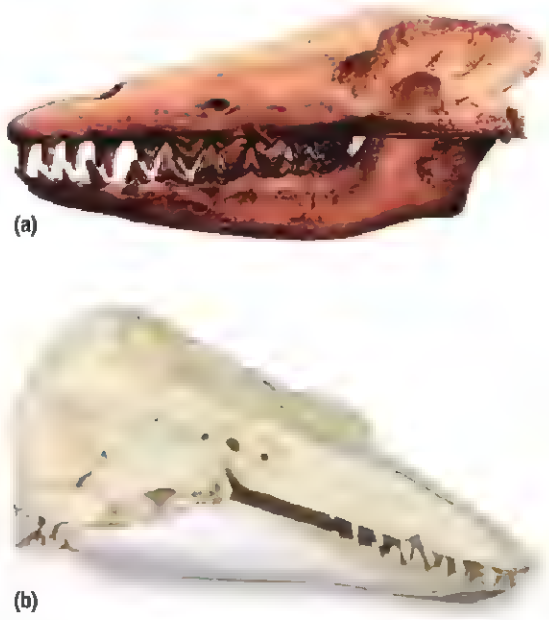

Figure 2 (a) Skulls of *Pakicetus* and (b) a modern whale

52. Describe how Neil Shubin used fossils to predict when the transition was made between fish and land vertebrates. (8.6) K/U
53. What makes humans unique as a species? (8.7) K/U

Understanding

54. Every year, millions of people worldwide receive seasonal flu shots. As a result, they build immunity against the human influenza virus. Why, then, are health organizations so concerned about the possibility of a deadly epidemic caused by the human influenza virus? (7.1) K/U

55. Wild tomato plants produce nutritious fruit of variable size. Plant breeders have now bred tomatoes with less variation. Why would uniformity in size be important in the modern food distribution system? (7.1) K/U

56. Why would maintaining genetic diversity in a population help breeders in their quest to produce dramatic changes in a population? (7.1) K/U

57. Paleontologists have observed that rock layers contain fossils of many species that do not occur in layers above or below them. Explain how this observation supports the theory of evolution. (7.2) K/U

58. Explain the roles that Lamarck believed inheritance and the environment played in evolution. (7.2) K/U

59. Describe the steps by which fossils are formed. List environmental conditions that are conducive to fossil formation. (7.2) K/U

60. Cave fish in the family *Amblyopsidae* that live in perpetual darkness have no eyes or tiny vestigial eyes. Lamarck might argue that this proves his principles of use and disuse. Why is that argument incorrect? What other explanation could there be for the loss of the fish's eyesight? (7.4) K/U

61. Explain why a dew claw is an example of a vestigial feature. (7.4) K/U

62. Do animals face greater competition from members of their own species or from other species in the ecosystem? Defend your opinion with examples. (7.4) K/U

63. Neither amphibians nor terrestrial flightless birds are capable of reaching a remote island by crossing the ocean. Amphibians are strictly freshwater species and terrestrial birds are not capable swimmers. If this is the case, why are large remote islands populated with many native species of flightless birds but not a single species of native amphibians? (7.4) T/I

64. As a scientist, why is it important to consider alternative explanations that might account for your findings when you test hypotheses? (7.4) K/U

65. Which of Darwin's observations support the inference that individuals of all species are in competition for resources? (7.5) K/U

66. Which of Darwin's observations support the inference that individuals inherit characteristics that increase their chance of reproductive success? (7.5) K/U

67. Explain how fossils provide evidence of relationships between primitive and modern species. (7.6) K/U

68. Dolphins have 1000 genes associated with a strong sense of smell, but they do not have a strong sense of smell. Explain why most of these smell genes are examples of pseudogenes. (7.6) K/U

69. The mushrooms of fungi like those shown in **Figure 3** have a number of interesting features. Comment on how each of the following might have influenced their evolutionary success. (8.1) K/U A
    (a) They are able to produce trillions of spores.
    (b) They have surprisingly little energy content when eaten.
    (c) Many species are highly toxic.

Figure 3

70. When individuals from a single species become separated by a geographical barrier such as a mountain range, they become less and less alike. Describe at least two reasons why this happens. (8.2) K/U

71. Explain how the process of speciation is analogous to the formation of a new language. (8.2) K/U

72. Explain how new species can evolve within a population either gradually or suddenly. (8.2) K/U

73. Explain the circumstances in which polyploid individuals can produce fertile offspring. (8.2) K/U

74. Explain how mechanical isolation could come into play during the mating flights of dragonflies or damselflies, shown in **Figure 4**. (8.2) K/U

Figure 4 Male and female migrant hawker dragonflies (*Aeshna mixta*) mating

75. Many marine animals, including corals and clams, release their sperm and eggs in open water. Which reproductive isolating mechanism would help ensure the right sperm and eggs combine? How might this work? (8.2) K/U
76. Why would the seemingly small difference of mating at different times of the day foster speciation? (8.2) K/U
77. Explain how Darwin's finches provide an excellent example of adaptive radiation. (8.3) K/U
78. Explain why sharks and dolphins provide a good example of convergent evolution. (8.3) K/U
79. What two outcomes can be predicted based on divergent evolution? (8.3) K/U
80. What two outcomes can be predicted based on convergent evolution? (8.3) K/U
81. What kinds of mass extinction events have occurred on Earth in the past, and why were they so biologically traumatic? (8.4) K/U
82. Although a crocodile would never be mistaken for a bird, scientists are convinced that birds are the closest living relatives of the crocodilians. What evidence supports this assertion? (8.5) K/U
83. It took billions of years for multicellular organisms to evolve from single-celled organisms on Earth. Why was this transition so important for the development of a huge variety of species on Earth? (8.5) K/U
84. What types of evidence (for example, fossils) are used to build phylogenies? Explain why each type of evidence would help to build these diagrams. (8.5) K/U
85. Explain the relationship between the terms "derived trait" and "synapomorphy." (8.5) K/U
86. When evolutionary biologists working with cladograms discuss a "primitive trait" or a "primitive condition," what does this mean? Are these traits crude relative to current capabilities? (8.5) K/U
87. Compare and contrast two theories used to explain patterns of evolution that occur over long periods of time. (8 5) K/U
88. How does Neil Shubin's work help other paleontologists to make predictions? (8.6) K/U

Analysis and Application

89. While in South America, Charles Darwin found fossilized armadillos and sloths. How did his observations about these species (both living and fossilized) support his theory of evolution? (7.3) T/I A
90. Charles Darwin spent a considerable amount of time observing marine iguanas (**Figure 5**). A special gland in its snout filters out salt from its blood, and the iguana then "sneezes" that salt out of its body. How did this adaptation allow the marine iguana to fill an available ecological niche in the Galapagos? What other adaptations would help this lizard take advantage of an underwater seaweed food supply? (7.3) T/I A

Figure 5

91. Provide examples to compare analogous and homologous features. Which features provide evidence of evolution? Explain. (7.4) T/I A
92. According to the theories of island biogeography, remote islands share many characteristics with land ecosystems that are surrounded by very different ecosystems (such as a park surrounded by areas inhabited by humans). There are, however, also some significant differences between "island" ecosystems on land and on actual islands. Describe two of these differences. (7.4) T/I A
93. Cane toads are giant poisonous toads from the Amazon rainforest. They were introduced into Australia in the 1930s to eat beetles that were causing crop damage. However, many native frog-eating species, such as snakes, are now dying from the cane toad's poison as the species spreads across Australia. Hypothesize how a toad from the Amazon could, over the course of a few decades, be flourishing in difficult desert terrain in Australia. (7.4) T/I A
94. Baby Burmese pythons are thought to have escaped during Hurricane Andrew from a breeding facility in Florida and ended up in the Everglades. Why would these snakes find this environment so inviting? (7.4) T/I A
95. Scientific theories such as cell theory, atomic theory, and the theory of evolution allow scientists to make accurate and precise predictions. Provide an example of such a prediction from any field of biology. (7.5) T/I A

96. Polar bears are thought to have evolved from brown bears several hundred thousand years ago. Hypothesize how this might have happened. (7.5) T/I A

97. Some antibiotics that are available only by prescription in the United States and Canada are available over the counter in parts of Asia. Why could this pose a problem in terms of quickly mutating bacteria? (7.5) T/I A

98. According to some evolutionary biologists, predators are extremely important to the health of an ecosystem. There is more biological diversity in ecosystems where top predators (such as wolves, sharks, or tigers) exist, and prey populations are far healthier. Hypothesize why the existence of predators might help, not hurt, prey populations. (7.5) T/I A

99. Scientists gain confidence in their theories when they find more than one kind of supporting evidence for them. What different types of evidence did Charles Darwin find for his theory of evolution? Given these different sorts of evidence, why do you think Darwin waited 20 years to publish his theory? (7.5) T/I A

100. Compare the speed with which advantageous and disadvantageous characteristics spread in populations. (7.5) T/I A

101. Scientific theories must, in principle, have the potential to be falsified. In other words, a theory is not scientific if there is no way to test it. (7.5) T/I A
    (a) How does dropping an apple "test" the scientific theory that explains gravity?
    (b) How does discovering a new fossil test the theory of evolution?
    (c) Describe what you might expect to happen in (a) and (b) if these theories were wrong.

102. Explain how half-lives of radioisotopes are used to obtain precise estimates of the age of rocks. (7.6) T/I A

103. Apply your knowledge of evolution to explain why antelope have eyes on the sides of their heads, with a broad radius of vision (**Figure 6**). (7.6) T/I A

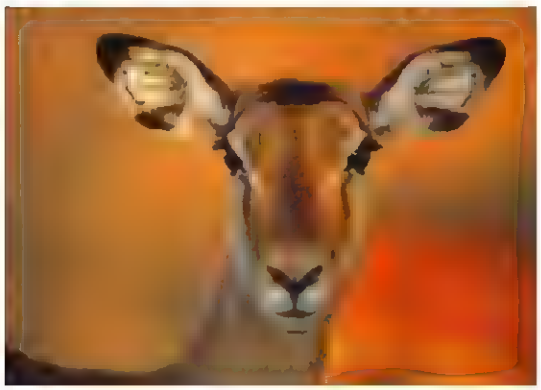

Figure 6

104. There are approximately 100 remaining Florida panthers in the Everglades. Florida panthers are a subspecies of mountain lions. Would bringing mountain lions into the Everglades from the Rockies help or hurt the Florida panther gene pool? Support your opinion. (7.6) T/I A

105. Consider the wings of penguins and emus. Which is a vestigial feature? Why? (7.6) T/I A

106. The leafy sea dragon (**Figure 7**) is one of the most bizarre looking animals on Earth. Use your understanding of evolution to
    (a) predict the type of habitat in which the sea dragon lives
    (b) name another animal to which it is closely related
    (c) describe a possible scenario to explain how natural selection resulted in the evolution of its unusual appearance (8.1) T/I A

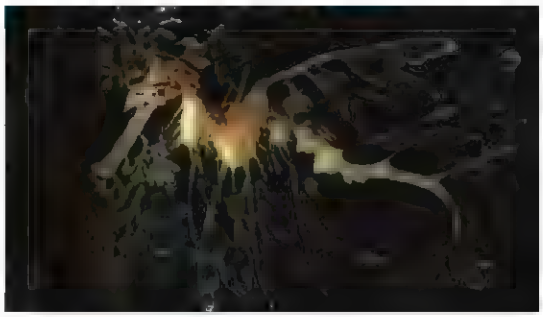

Figure 7

107. In the South Pacific, Papua New Guinea is home to only 7 million people. However, over 850 languages have developed in this country. How could this happen? (8.2) T/I A

108. Imagine a circumstance in which a large forest is fragmented into smaller areas due to agricultural and urban expansion and the construction of roads. Explain how such changes could lead to speciation and also threaten the survival of the populations. (8.2) T/I A

109. Why does adaptive radiation often come into play when a population is isolated in an environment with no competition other than members of the same species? (8.3) T/I A

110. The principles of convergent and divergent evolution allow scientists to make predictions, such as that different species will develop similar traits when placed under similar selective pressure. How do these predictions help scientists test the validity of the theory of evolution? (8.3) T/I A

111. Draw a cladogram based on **Table 1** of derived characteristics. Then interpret your cladogram to answer the following: (8.5) T/I A C

Table 1

Species	Derived characteristics				
	A	B	C	D	E
elephant	–	–	–	–	+
rhinoceros	+	–	+	–	+
rabbit	+	–	–	+	+
monkey	+	–	–	+	+
walrus	+	+	+	–	+
platypus	–	–	–	–	–

(a) Which species represents the outgroup?
(b) To which species are walruses most closely related?
(c) To which two species are rhinoceroses least closely related?
(d) Which derived characteristic provides no useful information for drawing this cladogram? Explain your reasoning.
(e) Were you surprised by the evolutionary relationships of these species? What does this suggest about the ability of species to change over time?

Evaluation

112. Examine Figures 4 and 5 on page 283 (Section 7.1). Based on their appearances, which two dogs appear to be most different? Is their degree of difference more or less than the difference between the wolf and the German shepherd (middle dog)? Does this evidence support the possibility that all dogs belong to the same species as wolves (*Canis lupus*)? (7.1) T/I A

113. On rare occasions, large snakes are born with tiny hind limbs. Using this fact, defend the conclusion that snakes are descended from an ancestor that walked on four legs. (7.4) C A

114. The theory of evolution is supported by many different kinds of evidence, including fossil evidence, anatomy, genetics, biogeography, and experimental results. How does this fact influence the confidence scientists have in the theory? (7.4) T/I A

115. Why did Darwin consider the ability to make predictions important to his theory? Provide examples to illustrate the predictive power of his theory. (7.5) T/I A

116. Paleontologists recently unearthed the first fossil of an extinct species of penguin. The bird, which lived 36 mya, was twice the size of Emperor penguins—the largest living species. The fossil was discovered in Peru, South America. Refer to Figure 7 on page 312 (Section 7.6). (7.6, 8.6) A

(a) Today's 17 penguin species can be found living in South America, Africa, Antarctica, Australia, and southern oceans, but none live in North America, Europe, or Asia. Why would this information not be surprising to evolutionary biologists?
(b) How might this fossil discovery be similar to that of *Tiktaalik*?

117. The spread and formation of human languages is sometimes used as an analogy for evolutionary change and even the formation of new species. Consider each of the following descriptions related to human languages and explain how they model processes or situations that occur in evolution. (8.2) A

(a) When people move to a new environment they create new words to describe their surroundings. For example, the Inuit have many words to describe snow while people living in the Amazon have none.
(b) When a small group of people are tested, they have a smaller vocabulary than that of the large population to which they belong.
(c) Canada seems to be the only country in the world where people are often heard to say "eh."
(d) A number of Canadians moved to Australia to live. It was noticed that after a few years they had all "picked up" Australian expressions and many even developed a slight Australian accent.
(e) Indigenous peoples of the world that are separated by very long distances all speak different languages and can not verbally communicate with each other.
(f) New research shows that human languages often change in rapid "bursts" rather than slowly and steadily.

118. What are some of the reasons why people are concerned by the increasing rate of species extinction? What are humans potentially losing as a result? (8.4) C A

119. From what you know of evolution, how can both gradualism and punctuated equilibrium play significant roles in evolution? What kinds of forces or events would result if each type of evolution came into play? (8.5) C A

Reflect on Your Learning

120. Like scientists, we all look for patterns in the world around us. How do patterns help us make sense of and live in our environments? K/U A

121. Assume that you are an entomologist, or insect scientist, and you have observed a female praying mantis eating a male praying mantis. Also assume you have looked in the scientific literature and found no description of this behaviour. Describe five steps you might take to help you develop and test a hypothesis regarding your praying mantis observation. T/I A

122. People breed both plants and animals to meet specific needs. Do you think there are significant differences in how plants and animals are bred? Think about the processes used for selective breeding, or the types of characteristics that are considered desirable in plants versus animals. Defend your answer with examples. K/U A

123. Lamarck's theories of evolution were both flawed and correct. If you were a scientist in his day, what kind of data would you collect to try to separate the truth from fallacy? And what would you do now, given the tools available to modern scientists? K/U A

124. In 1971, paleontologists in Mongolia found a fossilized velociraptor and protoceratops locked together in combat. The velociraptor had a claw in the throat of the protoceratops, and the protoceratops was biting down on the forelimb of the velociraptor. Hypothesize what happened to these animals. T/I A

125. Darwin began studying the role of earthworms in turning over soil and improving agriculture very early in his career. He came back to this pursuit later on in life. Some of these experiments involved placing stones on the ground, leaving them for decades, and then investigating whether worm action had caused them to sink. At the time, earthworms were considered pests. What conclusions can you draw about Darwin from this earthworm research? And what can young scientists in any field learn from this work? A

126. Does the theory of plate tectonics support the prediction that additional isolated island chains such as the Galapagos and Hawaii will be formed in the future? Why or why not? K/U A

127. How large a role do you think humans have had in the current rapid rate of extinctions on Earth? K/U A

128. What actions, if any, are you willing to take to educate others about the rate of mass extinction or to advocate for protection of Earth's species? Explain your answer. C A

129. How different do you think people's lives will be in 100 years, when many scientists predict that half of all living animal species will be extinct? A

Research

GO TO NELSON SCIENCE

130. Jason Gibbs, a York University doctoral student, recently published a study on "sweat bees." These tiny metallic-coloured insects are extremely similar and a nightmare to tell apart. In his painstaking research, Gibbs identified 19 new species, including one he collected on his commute from downtown Toronto to York University. Go online to find out the following: T/I
    (a) Why are these bees considered important to ecosystems?
    (b) How rapidly have sweat bees evolved?
    (c) Exactly where and how did Gibbs collect the new species in Toronto?
    (d) Is this new species of sweat bee rare?
    (e) How was Gibbs able to tell one species from another?

131. A very interesting outcome of evolution is the formation of "ring species." Go online to find out more about ring species formation. Research the distribution of *Ensatina eschscholtzi* salamanders in California. How has their geographic distribution influenced their evolution? T/I A

132. In September 2010, scientists reported the discovery of an astonishing new fossil deposit high in the Canadian Rockies. Research this important discovery and report back on the following: A C
    (a) Why is this discovery considered special?
    (b) How is it related to the famous Burgess Shale fossil site?
    (c) What types of fossilized animals have been found at the site?

133. During the past 50 000 years, well over half of large mammal species have become extinct. The two most likely causes are climate change and human action. Research the latest evidence in support of these two possible causes. Which one seems to have played the greater role? How might this information be valuable in our present situation? T/I A

134. The human appendix has been described as a vestigial feature. Explain why. Research the human appendix and briefly describe one to two hypotheses regarding the function it once played in human anatomy. T/I A

UNIT 4

Animals: Structure and Function

OVERALL EXPECTATIONS

- analyze the relationships between changing societal needs, technological advances, and our understanding of internal systems of humans
- investigate, through laboratory inquiry or computer simulation, the functional responses of the respiratory and circulatory systems of animals, and the relationships between their respiratory, circulatory, and digestive systems
- demonstrate an understanding of animal anatomy and physiology, and describe disorders of the respiratory, circulatory, and digestive systems

BIG IDEAS

- Groups of organs with specific structures and functions work together as systems, which interact with other systems in the body.
- The development and uses of technology to maintain human health are based, in part, on the changing needs of society.

UNIT TASK PREVIEW

As you progress through this unit, you will learn about the structure and function of selected organ systems and how they contribute to the health of an individual.

In the Unit Task you will create a health and fitness profile for an individual. You will then recommend an appropriate health and fitness plan for that individual. The Unit Task is described in detail on page 524. As you work through the unit look for Unit Task Bookmarks to see how information in the section relates to the Unit Task.

FOCUS ON **STSE**

WHOLE BODY SCANS

The image on the facing page makes the human body look somewhat transparent. The image shows whole body scans of (from left) a man, a nine-year-old boy, and a woman. The technology used to create these scans provides a way of looking through the body; we can see inside without actually going inside. One of the most important advantages of this technology is that we can see if there are abnormalities in any of the organs, without invasive tests or procedures.

Doctors usually use this scanning technology as a secondary procedure after other tests have indicated a potential problem in some organ or body system. There is a trend in some countries for private clinics to market whole body scans to healthy individuals as a preventive health measure. This marketing is based on two ideas: if your scan looks normal, then you have peace of mind and do not need to worry about your health; if the scan reveals an unsuspected problem, then you have the advantage of an early diagnosis and a more effective treatment of the condition.

If this technology is available, should we be using it routinely to screen everyone and look for early signs of cancer, heart disease, and other abnormalities? The answer to this question may seem obvious. But questions with seemingly easy answers should usually be examined more closely. We need to ask many other questions before making a decision. For example,

- How effective is this technology for identifying potential health problems?
- Are there other screening and diagnostic procedures that are more effective?
- Does a normal scan guarantee that you are perfectly healthy? Are there diseases and conditions that cannot be revealed by a whole body scan?
- What risks are involved in a whole body scan?
- What does a whole body scan cost? Who pays these costs? Do the benefits justify the costs?

Questions

1. In a small group, discuss the possible advantages and disadvantages of using whole body scans to screen for potential health problems. Consider each of the questions listed above and speculate on possible answers.
2. After considering the questions listed above, can you easily say whether it is a good idea to routinely screen everyone using whole body scans? Explain your thinking.
3. Recommend a guideline for doctors regarding the use of whole body scans and present it to your classmates.

UNIT 4 ARE YOU READY?

CONCEPTS

- identify and describe types of tissues
- understand the basic structure of organ systems
- understand the basic functions of organ systems
- describe interactions between organ systems
- explain the processes of diffusion and osmosis and their roles within a cell

SKILLS

- dissect a preserved specimen neatly and safely
- use scientific equipment accurately and safely
- research and collect information
- plan and conduct an experiment
- communicate scientific information clearly and accurately

Concepts Review

1. In your notebook, match each tissue on the left with the correct description on the right. K/U

(a)	epithelial	(i)	bundles of long cells containing protein capable of contracting (shortening)
(b)	muscle	(ii)	various types of cells held together by a liquid, gel, or solid, known as a matrix
(c)	connective	(iii)	long thin cells with finely branching ends capable of conducting electrical impulses
(d)	nerve	(iv)	thin layers of tightly packed cells covering surfaces and lining internal cavities

2. Describe the main function(s) of the tissues listed in Question 1. For each function, include an example of where it may take place within the body. K/U A

3. Copy **Figure 1** into your notebook. Add labels to identify which substances undergo diffusion and which undergo osmosis. Include arrows to show the direction in which diffusion and osmosis occur. K/U C

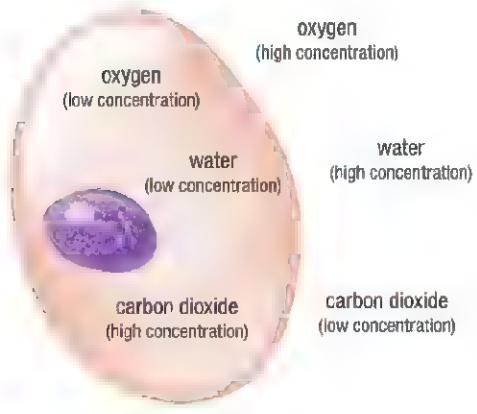

Figure 1

4. Define the term "semi-permeable." Why is it important for a cell membrane to be semi-permeable rather than completely permeable? K/U A

5. **Figure 2** shows a diagram of the human digestive system. In your notebook, match the following labels to the appropriate letter in Figure 2: liver, esophagus, large intestine, pancreas, stomach, small intestine. K/U

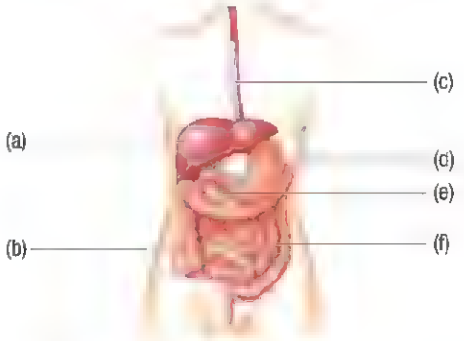

Figure 2 The human digestive system

6. In your notebook, match each structure on the left with the corresponding body system on the right. K/U

(a)	alveoli	(i)	respiratory
(b)	ventricles		
(c)	capillaries	(ii)	circulatory
(d)	gall bladder		
(e)	bronchi	(iii)	digestive
(f)	liver		
(g)	platelets		

7. Which of the following occurs during inhalation? K/U
   (a) diaphragm relaxes and air pressure in the lungs decreases
   (b) diaphragm relaxes and air pressure in the lungs increases
   (c) diaphragm contracts and air pressure in the lungs decreases
   (d) diaphragm contracts and air pressure in the lungs increases

8. Use a Venn diagram to compare and contrast the respiratory systems of fish and mammals. K/U C
9. Organ systems are interdependent—that is, they depend on one another and cannot function properly without other systems. K/U A
   (a) Explain how the respiratory system and the digestive system are dependent on the circulatory system.
   (b) Explain how the circulatory system is dependent on the respiratory system and the digestive system.
10. (a) Use a T-chart or other format to identify the possible benefits and risks of organ transplants.
    (b) What do you think is the main problem encountered by organ transplant programs? How might this problem be resolved? K/U T/I C A
11. A 50-year-old obese male has suffered a heart attack that was found to be a result of blocked arteries in his heart. Can you conclude that his obesity contributed to his condition? Explain your answer. K/U T/I A

Skills Review

The graph in **Figure 3** shows the observations recorded during an investigation. Carefully study the graph and answer Questions 12 to 17.

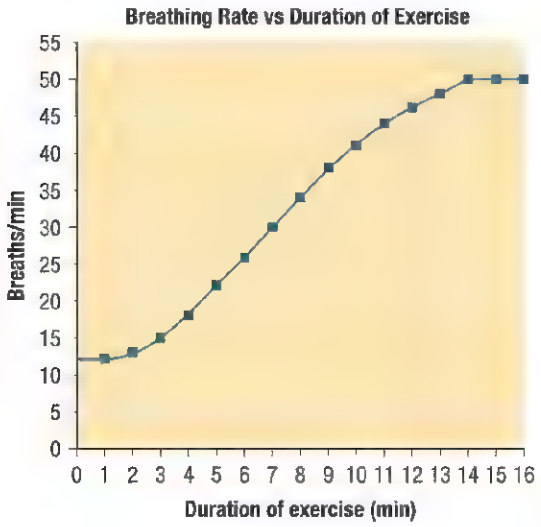

Figure 3

12. Which question do you think is the basis of the experiment? T/I A
    (a) How is the respiratory system affected by exercise?
    (b) How does the duration of exercise affect breathing rate?
    (c) Does exercise affect breathing rate?
    (d) How does the type of exercise affect breathing rate?
13. Which of the following statements represents a testable hypothesis for this investigation? T/I A
    (a) If the body produces more carbon dioxide during exercise, then exercise will increase the breathing rate.
    (b) If the body produces more carbon dioxide during exercise, then breathing rate will increase as the duration of exercise increases because more carbon dioxide will be expelled.
    (c) Exercise will increase the breathing rate because the heart beats faster during exercise.
    (d) If the body produces more carbon dioxide during exercise, then exercise will increase the breathing rate, because increasing the breathing rate will increase the amount of oxygen available.
14. What is the independent variable in this experiment? T/I A
    (a) duration of exercise
    (b) breathing rate
    (c) heart rate
    (d) type of exercise
15. What is the dependent variable in this experiment? T/I A
    (a) duration of exercise
    (b) breathing rate
    (c) heart rate
    (d) type of exercise
16. What variable should be controlled in this experiment? T/I A
    (a) duration of exercise
    (b) breathing rate
    (c) heart rate
    (d) type of exercise
17. Which of the following statements is most appropriate as a valid conclusion based on the evidence? T/I A
    (a) Strenuous exercise causes breathing rate to increase.
    (b) Breathing rate increases as the duration of exercise increases.
    (c) As the duration of exercise increases, breathing rate increases until it reaches a maximum rate.
    (d) Breathing rate is not affected by the duration of exercise.

CAREER PATHWAYS PREVIEW

Throughout this unit you will see Career Links in the margins. These links mention careers that are relevant to the structure and function of animals. On the Chapter Summary page at the end of each chapter you will find a Career Pathways feature that shows you the educational requirements of the careers. There are also some career-related questions for you to research.

CHAPTER 9

Nutrition and the Digestive System

KEY CONCEPTS

After completing this chapter you will be able to

- describe the importance and the requirements of an appropriate diet
- explain the overall function of the digestive system
- describe the structure and function of the main and accessory organs of the human digestive system
- summarize the processes that occur as food passes through the digestive system
- evaluate technologies that are used in the diagnosis and treatment of diseases or disorders of the digestive system
- demonstrate an understanding of common diseases and disorders and how they interfere with the main functions of the digestive system
- identify scientific achievements that advance our understanding of the digestive system
- conduct a controlled experiment to determine how different factors affect digestion

Does What We Eat Matter?

How do you think your daily diet compares with the diets of your classmates? How do you think it compares with the diets of students in other parts of the world? There are some distinct differences in diets among the various regions of Canada. For example, people in the Atlantic and Pacific coastal regions generally have more fish in their diets. People in the Prairies often have more beef and other meats available to them. People in the northern regions of Canada usually eat more wild game.

Around the world, people eat different foods prepared in different ways. Some cultures have diets based primarily on vegetables; others have diets based on meats. Some cultures eat more raw foods; others eat more cooked foods. There are endless varieties of food, and many different methods of preparing it. Despite all this variation, there is one important principle about food: we eat food to provide nutritional support to our bodies. The types of food we choose to eat can vary greatly, as long as we obtain the substances needed to grow, produce energy, and maintain life.

Almost all foods are of plant or animal origin. Regardless of the food source, the basic substances found in foods are the same. However, there are differences that make some diets more appropriate than others. For example, diets with a high proportion of food from plants are usually considered healthier than diets that have a high proportion of animal products. Diets with less highly processed foods are also generally healthier than those that are more processed. In addition, specific types of foods, such as certain fish oils, are particularly valuable, while others, such as fatty meats and sugars, should be minimized in a healthy diet. A healthy diet reduces the risk of health problems such as obesity and heart disease.

Our relationship with food is a vital one. It determines our survival and affects our health and quality of life. How much food do you need for your body to grow, repair, and maintain itself? Why are the kinds of substances you eat important? Which substances does your body require? How does your body get what you need from the food you eat?

In this chapter you will review the requirements of an appropriate diet—which substances we need and how much. You will also explore the structures and processes involved in converting the food we eat into materials that our bodies use for growth, maintenance, and energy.

STARTING POINTS

Answer the following questions using your current knowledge. You will have an opportunity to revisit these questions later, applying concepts and skills from the chapter.

1. Do you think the diets of some cultures are healthier than others? Explain your reasoning, providing two examples.
2. What foods do you consider to be important for a healthy diet? Explain your reasoning.
3. The human body needs certain substances in certain quantities in order to maintain good health. However, if the body takes in too much of a required substance, it can be hazardous to health. Why do you think this is the case? What does this tell you about the relationship between health and the nutritional value of food consumption?
4. Briefly describe the process by which our bodies obtain nutrients from the foods we eat.

Mini Investigation

Digestion Can Be a Mouthful!

Skills: Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK A2.1, A5.1

Your digestive system is highly specialized for physically and chemically breaking down foods to obtain nutrients. Both of these processes begin in the mouth.

Starch is an important food molecule found in many plants and is a major energy source in most human diets. Lugol's iodine stain can be used to detect the presence of starch. A colour change to blue/black is a positive test. In this activity, you will examine the process of chemical digestion involving starch that begins in your mouth.

Equipment and Materials: watch glass; unsalted soda cracker; Lugol's iodine stain

1. Place half of a soda cracker in your mouth and chew it for several seconds. Describe how the cracker tastes.
2. Let the cracker remain in your mouth for 1 min without swallowing or further chewing.
3. Can you detect any change in flavour? If so, what new flavour do you detect? Record this in your notebook.
4. Crumble a small piece of another cracker and place it on a watch glass.
5. Add one or two drops of Lugol's stain to the cracker on the watch glass. Record your observations.

A. What evidence was there that the cracker contained starch? TA

B. When you first placed the cracker in your mouth, what evidence was there that the cracker did not contain sugar? TA

C. What evidence suggests that a chemical change occurred in your mouth? TA

D. What substance in your mouth might be responsible for this chemical change? TA

E. What was the purpose of testing the cracker with Lugol's stain? TA

F. Use the Internet and other sources to research amylase—the chemical your body uses to digest starch. What kind of chemical is it and where it is produced in your body? TA

GO TO NELSON SCIENCE

9.1 Why We Need to Eat

On average, humans eat three times a day. If you spend 1 h eating each meal, that means you will spend 3 h, or 12.5 % of each day, eating. Eating is also a part of our social life. Many of our social interactions revolve around eating. We eat as a family, or we invite friends over or meet at a restaurant for a meal (**Figure 1**). Although eating may provide beneficial social interactions, the primary reasons for eating are to provide materials for growth and maintenance of our bodies, and to provide energy for all of our biological processes and activities.

Figure 1 Eating, an important part of our family and social lives, is also necessary for life.

Food for Growth and Maintenance

nutrient a chemical that must be obtained by an organism from its environment in order to survive; nutrients provide the raw material for growth and repair and may be a source of energy

We obtain the raw materials for growth and maintenance of our bodies from nutrients in food. **Nutrients** are the chemicals that an organism needs in order to grow, build, and repair tissues, and to produce energy. The nutrients that are important for keeping our bodies healthy are carbohydrates, proteins, lipids (fats), water, minerals, and vitamins. You will learn more about these nutrients in the next section. Once in the body, most nutrients are broken down into simpler molecules that are then used to build bone, muscle, and other types of cells and tissue. Damaged cells are repaired, dead cells are replaced, and, in growing organisms, new cells are produced.

Food for Energy

Nutrients provide the energy that fuels all biological processes. As you learned in your previous science studies, most of this energy begins as light energy from the Sun, which is converted into chemical energy by plants during the process of photosynthesis. Unlike light energy, chemical energy can be stored in cells and then released when needed. All organisms require chemical energy to perform basic life functions.

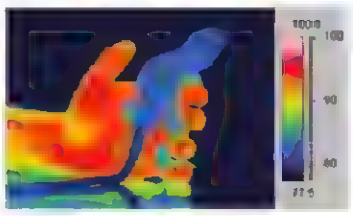

Figure 2 All animals lose thermal energy, some more than others. Note that the reptile is much cooler than the human. Why is that?

Animals eat in order to obtain chemical energy. The chemical energy produced by plants is transferred to herbivores and omnivores. Humans obtain the chemical energy carried in animal and plant based food. Cells in the body use chemical energy to fuel biological processes and physical activities, such as growth and movement. In endothermic (warm-blooded) animals, some of this energy is used to maintain a fairly constant body temperature, but eventually, the energy is converted into thermal energy and is transferred back to the environment. Normally, the temperature of the human body is higher than that of its surroundings, which means that we are continuously transferring thermal energy to the environment (**Figure 2**).

If you are sitting reading this book, you may think that you are not using much energy. However, there are many processes going on inside your body—your heart is beating, you are breathing, your brain is processing information, your muscles are holding you upright in your chair, and you are transferring thermal energy to the air around you. All of these processes require energy.

Factors That Affect Energy Requirements

Some living things require much more food than others. Endothermic animals—mammals and birds—need a great deal of energy to keep their bodies warm and therefore must consume a greater quantity of food than ectothermic (cold-blooded) animals of equal size. A shrew, for example, needs to eat more than two-thirds of its body mass in food every day in order to have enough energy to stay warm (**Figure 3(a)**). Ectothermic animals, on the other hand, survive on much less food. A similar sized frog, for example, could easily survive for a month on the same amount of food as a shrew needs to eat every day (**Figure 3(b)**).

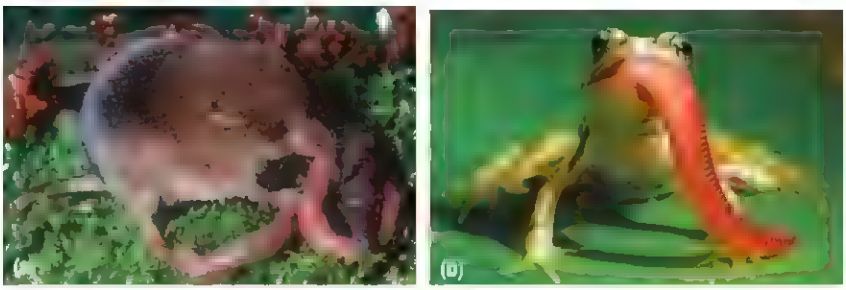

Figure 3 (a) This shrew must consume a large amount of food every day. (b) This frog can survive for weeks on one good meal.

Size is also a factor in determining how much an animal needs to eat. Larger animals generally eat more food than smaller ones. However, in the case of endothermic animals, the relationship is a bit more complex. Small endothermic animals need to eat more food for their size than large endothermic animals. For example, a 5000 kg elephant might eat 250 kg of food a day—5 % of its body mass. A 5 g shrew might have to eat 4 g of food a day—80 % of its body mass!

In order to stay alive, your body performs many different chemical reactions. All of these chemical reactions are collectively referred to as your **metabolism**. One part of metabolism, called **catabolism**, involves the breakdown of materials in an organism. The chemical and physical breakdown of nutrients during digestion is an example of catabolism. Another part of metabolism, called **anabolism**, involves the building of larger, more complex molecules from smaller, simpler molecules. An example of anabolism is the use of materials and energy provided by catabolic processes to build the complex materials needed for growth and repair.

The rate at which the body converts stored energy into working energy is called **metabolic rate**. Everyone's metabolic rate is different. This is because metabolic rate depends on a number of factors. Generally, the following trends apply:

- Body size: The larger the body, the more energy is required to stay alive.
- Physical activity: Muscle burns more energy than fat, so physical activity requires more energy.
- Sex: Males are typically larger in size and have a greater proportion of muscle mass than females of the same size, age, and fitness level.
- Age: Metabolic rate decreases with age (in part due to decreased physical activity and the loss of muscle mass).
- Hereditary factors: Some individuals have a naturally high metabolic rate. In these individuals, the chemical energy obtained from food is very quickly converted into other forms of energy.

As these trends indicate, someone who is smaller in size may still require more energy than a larger person if he or she has a higher level of physical activity. Similarly, a person in her sixties who leads a very active lifestyle may still have a lower metabolic rate than a person in her teens who is only moderately active. There is no steadfast rule that can be applied to metabolic rate; these are trends.

metabolism the set of chemical reactions that occur in living organisms that are necessary to maintain life

catabolism the metabolic reactions that break down larger molecules into smaller subunits

anabolism the metabolic reactions that use energy to produce larger molecules from smaller subunits

metabolic rate the rate at which the body converts stored energy into working energy

Measuring Energy

Energy is measured using an SI unit: the joule (J). Since the joule is a relatively small unit of energy, we often use the kilojoule (kJ) to refer to the energy requirements of people or the energy stored in foods (1 kJ = 1000 J).

Recall from previous grades that a calorie (small *c*) is the amount of energy required to raise the temperature of 1 g of water by 1 °C. When referring to food energy, another unit—the Calorie—is often used. One Calorie (with a capital C) equals 1000 calories, or 4180 J. The energy in food is often described in terms of Calories. Nutrition labels, for example, provide the energy value of food in Calories.

The rate at which energy is used by an organism when it is at rest is referred to as the **basal metabolic rate** (BMR). This is the amount of energy you would use per day if you stayed in bed all day, with your body performing only vital processes (such as breathing and heartbeat). The BMR for a person can be accurately calculated based on the consumption of oxygen, but it is a complex process and not practical for everyday use. The BMR is generally estimated using a calculation that takes into account four variables: height, weight, age, and sex. Males tend to have a higher BMR than females by about 10 %. Your energy requirements also depend on your activity level.

LEARNING TIP

Muscle-to-Fat Ratio

The limitation of the BMR calculation is that it does not take into account the ratio of muscle to fat in the body. While it is a good guideline for most people, it does not provide an accurate value for very muscular or very overweight individuals.

basal metabolic rate the minimum amount of energy required to keep you alive

Mini Investigation

How Much Energy Do You Need?

Skills: Observing Analyzing

SKILLS HANDBOOK A2.1, A6.2

In 1918, J. Arthur Harris and Francis G. Benedict, nutrition researchers at the Nutrition Laboratory of the Carnegie Institute of Washington, published a paper based on their study of basal metabolism. The data from their research allowed them to derive a formula that is still the most commonly used method of estimating basal metabolic rate and energy expenditure.

Your BMR is unique to you. It depends on your sex, size (height and mass), and age. The Harris–Benedict formulas for estimating your BMR are as follows:

female

$$\text{BMR} = [655 + (9.6 \times \text{mass in kilograms}) + (1.8 \times \text{height in centimetres}) - (4.7 \times \text{age in years})] \times 4.18$$

male

$$\text{BMR} = [66 + (13.7 \times \text{mass in kilograms}) + (5.0 \times \text{height in centimetres}) - (6.8 \times \text{age in years})] \times 4.18$$

Example:

Tom is a 16-year-old student who is 175 cm tall with a mass of 75 kg. Estimate his BMR.

Solution:

Use the formula for males and substitute the values as follows:

$$\text{BMR} = [66 + (13.7 \times 75) + (5.0 \times 175) - (6.8 \times 16)] \times 4.18$$

$$\text{BMR} = 7773.5 \text{ rounded to } 7800 \text{ kJ}$$

The Harris–Benedict formula uses the following activity factors in conjunction with the BMR to estimate the average individual daily energy requirement.

- little or no exercise — BMR × 1.2
- light exercise or sports 1–3 days/week — BMR × 1.375
- moderate exercise or sports 3–5 days/week — BMR × 1.55
- vigorous exercise or sports 6–7 days/week — BMR × 1.725
- very hard exercise daily or sports & physical job or 2 × training daily — BMR × 1.9

For example, Tom is a fairly active student who plays sports most weekdays. Therefore his average daily energy requirement will be 7800 kJ × 1.55 = 12 090 kJ rounded to 12 000 kJ.

1. Use the appropriate formula to estimate your BMR.

A. Analyze your lifestyle in terms of your level of activity. Multiply your BMR by the appropriate activity factor to estimate your daily energy requirement. T/I A

Your energy requirement is not the same each day; it varies with the type and amount of physical activity that you do. You can more accurately estimate your energy requirement by analyzing your activities each day and adding up the amounts of energy required for each activity. **Table 1** (next page) shows the energy requirements for various activities. Note that the units are in kJ/kg/h. This is the energy (kJ) that you need for each kilogram of body mass, to perform the activity for 1 h.

Table 1 Average Energy Requirements for Various Activities

Type of activity	Energy required (kJ/kg/h)	Type of activity	Energy required (kJ/kg/h)
sleeping	4.1	walking (6.4 km/h)	20.6
sitting	5.2	badminton	21.5
writing	6.0	mowing lawn	23.0
standing	6.3	cycling (15.3 km/h)	25.8
singing	7.1	hiking, fast dancing	27.0
using a computer keyboard, playing cards	9.0	tennis, downhill skiing	36.2
washing the car, cooking	10.5	climbing stairs, running (8.8 km/h)	37.5
playing the piano	11.2	cycling (20.9 km/h)	40.5
walking (3.2 km/h)	11.6	cross-country skiing	42.0
cycling (13 km/h)	15.8	running (12.9 km/h)	62.0
walking (4.8 km/h)	16.2	competitive cross-country skiing	73.6

9.1 Summary

- All animals must eat to obtain materials for growth and repair and to obtain energy for all life processes.
- All of the chemical reactions that occur in an organism are referred to as the organism's metabolism. These reactions include the breakdown of materials to provide energy and the construction of materials for growth and repair.
- The basal metabolic rate (BMR) is the minimum amount of energy required to keep an organism alive. It can be estimated using a formula that takes into account the individual's sex, age, height, and mass.
- Your daily energy requirement depends on your BMR and level of physical activity.

UNIT TASK BOOKMARK

Consider what you have learned about basal metabolic rate and energy requirements. How will this information be useful to you in Parts A and B of the Unit Task?

9.1 Questions

1. What are two factors that determine how much an animal needs to eat? K/U
2. How and why is our energy requirement affected by each of the following factors: physical activity, body size, sex? K/U A
3. Using the values in Table 1 (above), estimate how much energy you will need for the current 24 h period, starting at midnight last night. Include a complete list of your activities (both completed and planned) and the estimated time and energy requirement for each activity. T/I A
4. Paul and his friends ate at a fast-food restaurant. Paul, who has a mass of 70 kg, had a cheeseburger, fries, and a large drink. These items provide a total of 2500 kJ of energy. T/I
   (a) How long would Paul have to play a computer game in order to use this much energy?
   (b) How long would he have to run to use this much energy?
   (c) If Paul walked at 6.4 km/h for 2 h, do you think he would use up all the energy from his meal? Explain, showing your calculations.
5. Compare the workday energy requirements of an office worker and a letter carrier. (Assume that these individuals are both of the same sex and body size.) K/U A
6. Use the Internet and other sources to find values for the average daily energy requirements for people of different ages and levels of activity. Using this information, what would be the daily energy requirement for
   (a) an active 5-year-old girl?
   (b) an inactive 65-year-old man?
   (c) a very active 16-year-old male?
   (d) a very active 16-year-old female? T/I

GO TO NELSON SCIENCE

9.2 What and How Much We Need to Eat

Your body needs six essential nutrients in order to stay healthy: carbohydrates, proteins, lipids, water, vitamins, and minerals. These are the building blocks of life. If any of these nutrients are absent from your diet for too long, your cells will stop working properly.

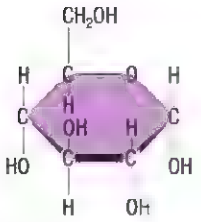

Figure 1 Monosaccharides, such as glucose, consist of a single sugar molecule.

Carbohydrates

Carbohydrates are the main source of energy for the human body. Carbohydrate molecules are made up of carbon, hydrogen, and oxygen. There are three main types of carbohydrates: monosaccharides, disaccharides, and polysaccharides. The most basic carbohydrates are monosaccharides, or simple sugars, which are ring-shaped structures consisting of a single sugar molecule. Glucose and fructose are examples of monosaccharides. Glucose is used during cellular respiration to provide the energy needed for cellular processes and physical activity (**Figure 1**). Disaccharides, as the name suggests, are made up of two simple sugars joined together. Sugars such as lactose (milk sugar) and sucrose (table sugar) are examples of disaccharides.

Many simple sugar molecules can join together to form large carbohydrates called polysaccharides. Polysaccharides are also referred to as complex carbohydrates; a single polysaccharide molecule may consist of hundreds of joined simple sugars. Starches and cellulose are polysaccharides made and stored in plants. Most starches are branched chains of glucose molecules. Unlike starches and most other polysaccharides, cellulose has a straight rigid structure (**Figure 2(a)**). Glycogen is a polysaccharide that is made and stored in animals. Glycogen is more highly branched than plant starches (**Figure 2(b)**).

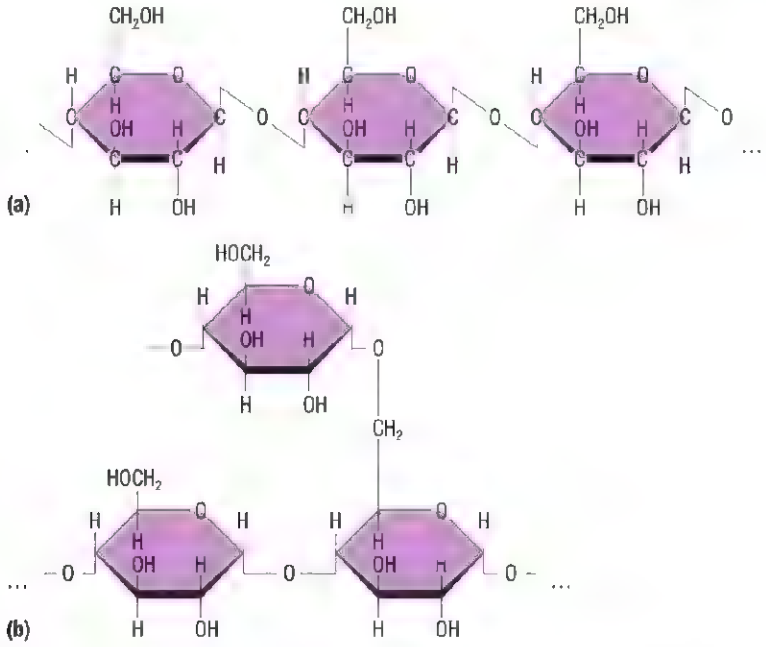

Figure 2 (a) Cellulose, the polysaccharide that provides the structure for plant cell walls, consists of many glucose units. (b) Glycogen, an energy-storing carbohydrate in animals, is a long branching chain of glucose units The above diagrams represent small portions of much larger molecules.

Carbohydrates are a major part of plant cell structure. Plants use the carbohydrates they produce for energy and to create complex molecules, such as cellulose. Cellulose is used in plant cell walls to give the plant structure. Excess sugars produced during photosynthesis are stored by plants as starch in their roots, stems, leaves, and seeds.

A healthy diet is generally considered to be one in which carbohydrates provide at least 55 % of a person's energy needs. Foods high in carbohydrates include vegetables, potatoes, and grains (**Figure 3**). Many grains, fruits, and vegetables contain cellulose. Humans cannot digest cellulose, but it provides fibre, which is an important part of a healthy diet. Plant starches are the main source of chemical energy for humans and are an important component of the diet. Complex carbohydrates, such as starches, must be broken down into simple sugars, such as glucose, before the body can use them. In humans, carbohydrates are stored in the liver and muscle tissues in the form of glycogen. If the maximum amount of glycogen is stored, excess carbohydrates can be converted to lipids and stored as body fat. When energy is needed, glycogen is converted back into usable glucose.

Figure 3 Plants and plant products are a source of dietary carbohydrates.

Proteins

Proteins are one of the key building blocks of cells and perform a wide range of functions. They are important structural molecules, are involved in all metabolic activities, and are used to generate motion. Some proteins serve as **hormones**—chemical messengers released by cells in the body that influence cellular activity in another part of the body. Main protein functions and examples are listed in **Table 1**.

hormone a chemical signal or messenger molecule circulated through the body and used to coordinate cellular functions

Proteins are the most complex of all nutrients. Proteins are made up of long chains of smaller molecules called amino acids and are highly variable in size and shape (**Figure 4**). There are 20 different amino acids that organisms use to build proteins. The human body can make 12 of these amino acids, but must obtain the other 8 amino acids from food sources. The 8 that must be obtained from food sources are called essential amino acids.

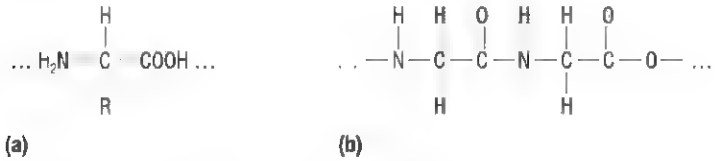

Figure 4 (a) Amino acids consist of a central carbon atom attached to a single hydrogen atom; an amino group (H_2N), a carboxyl group (COOH), and a side chain (represented by R) that varies among the 20 different amino acids. (b) Proteins are formed when many amino acids are joined together. The above diagrams represent only small portions of much larger molecules.

There are many animal and plant sources of protein. Animal sources that are high in protein include meat, eggs, fish, and cheese. Plant sources high in protein include beans, lentils, seeds, and nuts. Animal proteins contain all eight essential amino acids. However, most plant proteins lack at least one essential amino acid. Therefore, people who do not eat animal products must eat plant foods in combination to obtain all the amino acids they need. Furthermore, animal muscle has a higher concentration of protein than plant material, so you have to eat a greater mass of plant material to obtain an equivalent amount of protein. For example, a 225 g steak provides approximately 48 g of protein, which is almost enough protein to meet the daily requirements (about 60 g) for an adult. To get 60 g of protein, you would need to eat 15 cups of raw vegetables. When you eat proteins, your body separates the proteins into individual amino acids so they can be rearranged and used as building blocks for human proteins. Regardless of the source, the recommended daily diet for youths 14 to 18 years old should provide 0.85 g of protein for each kilogram of body mass.

Like carbohydrates, protein can also be used to provide energy, and excess protein can be converted into high-energy storage molecules. However, since proteins have so many important functions, they form a relatively small portion of energy in an individual's diet. Health Canada recommends that 10 % to 30 % of your average energy requirements should come from protein.

Table 1 Functions of Proteins

Function	Example
control of chemical reactions	digestive chemicals
movement	myosin in muscle cells
transporting oxygen	hemoglobin in red blood cells
structure	collagen in muscles and connective tissue; keratin in hair and nails
hormones (chemical messengers)	human growth hormone
defence	antibodies produced by the immune system
source of energy	excess proteins from diet

Lipids

Lipids provide a concentrated source of chemical energy for the body. They help in the absorption of vitamins, are a main component of cell membranes, and serve as insulation for the body. Certain hormones, including sex hormones, are lipids.

triglyceride a lipid composed of glycerol and three fatty acids that are bonded together

Fats and oils are two familiar types of lipids. Fats and oils are made up of three fatty acids bonded to a glycerol molecule, which make up a **triglyceride**. Triglycerides can be either saturated or unsaturated, depending on the structure of their fatty acid chains. Fatty acids contain long chains of carbon and hydrogen atoms (**Figure 5**). Unsaturated triglycerides (unsaturated fats) are called oils, and they are usually liquid at room temperature. Plant and fish oils are common sources of unsaturated fats. Saturated fats are usually solid at room temperature. Meat and butter are common sources of saturated fats. Unsaturated fats are often thought of as good fats. Studies have shown that people who follow a diet rich in plant oils are often much healthier than people whose diet is rich in animal fats (**Figure 6**).

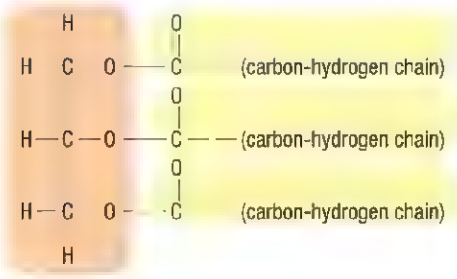

Figure 5 The fatty acid molecules in triglycerides vary in length, depending on the type of lipid. The above diagram represents only a small portion of a much larger molecule.

Figure 6 Unsaturated fats are generally considered healthier than saturated fats.

WEB LINK

For more information on the health benefits of omega-3 fatty acids,

GO TO NELSON SCIENCE

Some fatty acids are referred to as essential; that is, they cannot be produced in the body and must be obtained from the diet. One of these essential fatty acids is called omega-3 fatty acid. Omega-3 fatty acids are in unsaturated fats and are very important in maintaining good health and preventing health problems such as heart disease and arthritis. They are found in a variety of foods including oily fish (such as salmon, mackerel, herring, and tuna), nuts, seeds, and leafy green vegetables.

A special group of lipids called steroids includes the sex hormones testosterone and estrogen, and cholesterol. Sex hormones control the development of male and female sex characteristics. Cholesterol is a key component of all animal cell membranes. Like saturated and unsaturated fat, cholesterol has good and bad forms. You will learn more about the role and impact of cholesterol in Chapter 11.

Fats usually raise a warning flag when we think about healthy eating, but they are important components of any diet. In a healthy diet, lipids should constitute no more than 30 % of energy intake. Excessive consumption of lipids can cause serious health problems such as heart disease and obesity. Trans fats are a particularly harmful type of lipid. They are a type of unsaturated fat, but they behave like saturated fats. Trans fats pose an even higher risk of heart disease than saturated fats because they raise bad cholesterol levels and lower good cholesterol levels.

Water

Your body is made up of 55 % to 60 % water. In addition to the water required in cell cytoplasm, your body also requires water for chemical reactions, to digest food, and to eliminate waste products. Water is also necessary to maintain your blood volume, to regulate body temperature, and to keep your skin moist. Water is necessary for life. In addition to the water obtained through food intake, humans need to drink about 2 L (8 cups) of water per day. This replaces the water lost through urine, sweat, and respiration.

Vitamins and Minerals

A **vitamin** is a compound that an organism needs as a nutrient only in small amounts. Vitamins regulate cell functions, growth, and development within our bodies.

Vitamins are classified as either fat soluble (will dissolve in fats) or water soluble (will dissolve in water). Vitamins A, D, E, and K are fat soluble and can be stored in the body's fatty tissues for future use. These vitamins do not dissolve in water and are therefore not easy to eliminate from the body if they are in excess. Taking high doses of these vitamins can lead to toxic levels in the body. Vitamins B and C are examples of water-soluble vitamins. They cannot be stored in the body, and excess quantities are readily excreted in urine. Water-soluble vitamins must be replenished daily through diet.

We obtain most of our vitamins from food, but vitamins A, D, and K can also be produced in our bodies. For example, the body can convert a chemical called beta-carotene into vitamin A. Beta-carotene is found in foods such as green vegetables, carrots, egg yolks, and liver. Vitamin D is often called the "sunshine" vitamin, because it is formed in the skin when the skin is exposed to sunlight. Our bodies can produce enough vitamin D from 10 min to 15 min of sunshine three times a week. Vitamin K is synthesized by special bacteria found in the large intestine.

Our bodies also need minerals to maintain health. **Minerals** are naturally occurring elements that the body uses to carry out metabolic processes and to build or repair tissues. Calcium and phosphorus, for example, are critical in the formation of bone. Sodium is involved in nerve impulse transmission and in muscle contraction. Iron is a key component of the blood protein hemoglobin. Oxygen binds to the iron component of hemoglobin and is transported throughout the body. Calcium, phosphorus, sodium, and iron are prominent in our bodies. Other minerals, such as fluorine, zinc, and copper, are present in our bodies in trace amounts.

vitamin an organic molecule that the body requires in small amounts as an essential nutrient

WEB LINK

There is some concern that an indoor lifestyle and lack of routine exposure to sunlight may be resulting in a vitamin D deficiency for many Canadians. To find out more about this and other vitamin deficiencies,

GO TO NELSON SCIENCE

mineral an element, such as calcium or phosphorus required by the body in small amounts; plays a role in cell processes and repair

Healthy Eating

To promote healthy eating habits, Health Canada publishes *Eating Well with Canada's Food Guide*, which recommends how much of which types of foods we should eat each day (**Figure 7**). The recommendations include foods that supply appropriate amounts of carbohydrates, proteins, and lipids, as well as essential vitamins and minerals. A dietitian can provide professional advice on how to maintain a healthy diet or when a health problem requires adjustments to the diet.

CAREER LINK

Dietitian

To learn about becoming a dietitian,

GO TO NELSON SCIENCE

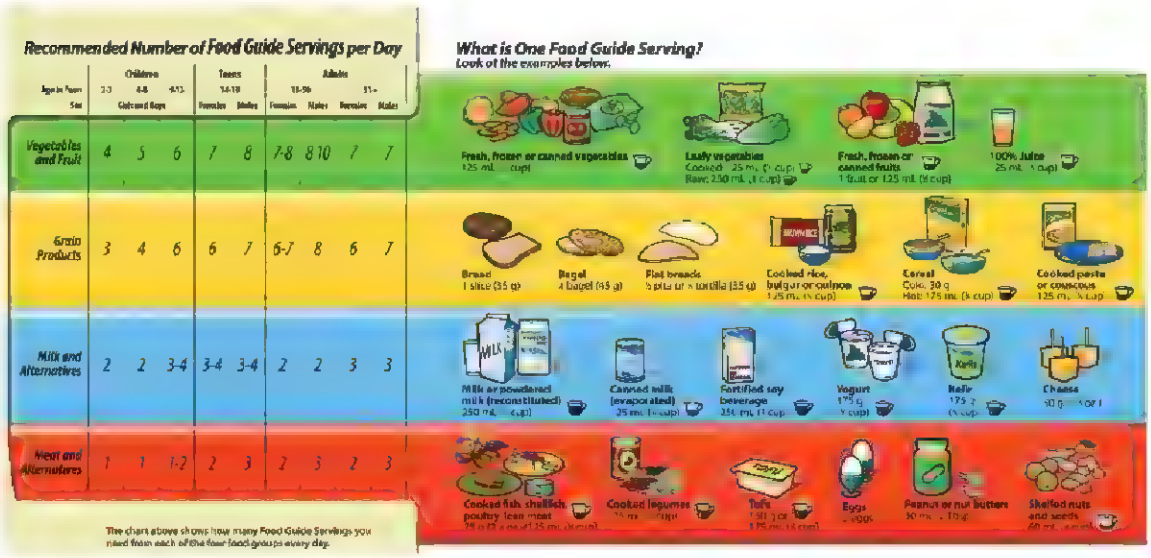

Figure 7 Following Health Canada's *Eating Well with Canada's Food Guide* is the first step to a healthy diet. The guide can be customized to suit many types of diets.

Maintaining a Balance

In addition to eating the right kinds of foods, we have to ensure that we eat the right amount of food. The food guide provides guidelines for the number of servings and appropriate serving size of each food category. The challenge is to find the right nutrient balance so that energy intake equals energy output.

Maintaining your body mass requires that the average energy output equals the average energy input. In other words, the amount of energy you use in metabolic processes must equal the amount of energy obtained from the food you eat. A disruption in balance can cause weight loss (energy input is less than energy output) or weight gain (energy input is greater than energy output).

There are three variables in maintaining a balance: level of physical activity, amount of food consumed, and type of food consumed. Increasing physical activity increases the output of energy. Reducing the amount of energy taken in can be achieved by simply reducing the total amount of food consumed. However, it is more effective to simply eat foods that have lower energy content. One gram of carbohydrate or protein provides about 17 kJ of energy in the body. One gram of fat, however, provides about 38 kJ. Thus, a diet that has a low proportion of lipids is generally considered a healthy diet.

How much should you weigh? How much should you eat? What kinds of foods should you eat? These are questions that do not have easy answers. Nonetheless, some physical and psychological problems are directly related to what, how much, or how little we eat.

LEARNING TIP

Body Mass Index

Body Mass Index (BMI) is the ratio of a person's height and weight. It is used to estimate whether a person has a healthy body weight for his or her height. BMI is calculated using the following equation:

$$BMI = \text{weight (kg)} \div \text{height (m)}^2$$

BMI is an estimate of the relative amount of body fat. It is a widely accepted method to screen for potential weight problems because it is inexpensive, convenient, and reliable.

Overeating

Obesity is a condition where an excessive amount of body fat poses potential health risks. In some cases, genetic factors contribute to obesity. In the majority of cases, inappropriate diet and inactivity combine to produce weight gain and obesity.

Despite all we know about the importance of a healthy diet and physical activity, research shows that the percentage of overweight and obese people is increasing in Canada. Access to fast food and other high-fat and sugary foods is a major factor contributing to this rise in obesity rates. Being overweight or obese increases the risk of many medical conditions, including heart disease, respiratory problems, diabetes, cancer, high blood pressure, and joint problems. Because obesity can lead to health problems, it has potential social and economic implications related to productivity and the cost of providing healthcare.

Anorexia Nervosa

Some individuals become obsessed with losing weight to the point of severe malnutrition. Anorexia nervosa, or simply anorexia, is a psychological disorder that usually begins with dieting and progresses to extremes such as severe dieting, excessive exercising, and use of laxatives, diet pills, and even enemas in order to lose weight. Laxatives are medications that cause food to pass through the intestines more quickly than normal. An enema involves flushing the bowels with liquids. Even when severely underweight and close to starvation, people suffering from anorexia perceive themselves as overweight and do not recognize that they have a problem. The health complications resulting from anorexia can become life-threatening. Estimates are that 10 % of anorexia cases end in death.

Bulimia

Bulimia is another common psychological eating disorder. Bulimia usually involves excessive eating followed by self-induced vomiting or laxative use to prevent weight gain. This pattern is referred to as binge–purge behaviour. Many individuals with bulimia also suffer from anorexia. Unlike people with anorexia, a person who suffers from bulimia recognizes that his or her behaviour is abnormal and may feel guilty about it.

Like anorexia, there are many risk factors associated with bulimia that usually include a psychological component. Depending on the severity of the symptoms and related health problems, treatment of eating disorders usually involves behavioural and nutritional therapy. Treatment for eating disorders is always challenging and requires a strong commitment from the individual and continuous support from family and friends to prevent a relapse.

9.2 Summary

- The nutrients that we obtain from our food are carbohydrates, proteins, and lipids. Generally, carbohydrates and lipids are energy nutrients. Amino acids from food are used to construct a variety of proteins that have numerous functions in the body.
- Vitamins and minerals are important to maintaining good health, and water is an essential substance for survival.
- The key to maintaining a healthy weight is to ensure that the energy intake is balanced by the energy output. This can be achieved by a combination of a healthy diet and an appropriate level of physical activity.
- In a large majority of cases, obesity is the result of overeating, an unhealthy diet, and inactivity.
- Eating disorders such as anorexia and bulimia are psychological disorders that can lead to serious physical health risks.

UNIT TASK BOOKMARK

Consider what you have read about nutrients and healthy eating. How can this information help you create a health and fitness plan in the Unit Task?

9.2 Questions

1. (a) Create a table to compare carbohydrates, proteins, and lipids. Your comparison should include the functions of each group of nutrients, examples of foods that contain each type of nutrient, and any other criteria that you think are important.
   (b) What other nutrients are necessary for good health? K/U
2. (a) Estimate and record the type and amount of food you eat in one day. How does your food intake compare with the recommendations of Health Canada's food guide?
   (b) Do you think that this sample is representative of your overall diet? Explain. T/I C A
3. Obesity is a growing problem in Canada, especially among children and youth. Use the Internet and other sources to research the current statistics on the incidence of obesity in Canada, and prepare a brief report of your findings. In addition to summarizing your findings, answer the following questions in your report. T/I C A
   (a) Do you think there are childhood and youth obesity issues in your community? What evidence do you have?
   (b) What do you think are the main factors that contribute to this problem in Canada and/or your community?
   (c) What measures do you think should be taken to address the problem in Canada and/or your community?
4. The dietary goal of a sumo wrestler is to gain weight. Use the Internet and other sources to research the strategies used by sumo wrestlers to gain weight. T/I C A
   (a) In addition to eating a lot of food, what strategies do sumo wrestlers use to gain weight?
   (b) What health risks do sumo wrestlers face?
   (c) What lessons can be learned from a sumo wrestler's approach that might help with weight loss?
   (d) Do you think a sumo wrestler represents a healthy individual? Explain your answer.
5. (a) How are anorexia and bulimia similar? How are they different?
   (b) Why are these disorders difficult to treat?
   (c) What do you think would be an appropriate response if you suspect that a friend has an eating disorder? K/U A
6. Use the Internet and other sources to research anorexia and bulimia. Are these disorders more common among males or females? What age group is most affected? K/U T/I
7. (a) The discipline of molecular gastronomy is a recent area of study related to food and nutrition. Use the Internet and other sources to research molecular gastronomy. Write a brief report of your findings.
   (b) Do you think molecular gastronomy is a scientific discipline? Why or why not? K/U

GO TO NELSON SCIENCE

9.3 Introducing Digestion

Figure 1 The mosquito's mouth structure can puncture the skin and a small artery without the host being aware of it.

gastrovascular cavity a simple, sac-like digestive cavity that has only one opening through which food is taken in and wastes are expelled

Food contains the nutrients we need but not in a form that our bodies can use directly. The food we eat must be broken down into nutrients that can then be absorbed into the blood and carried to the cells of the body. This process is called digestion. The collection of organs that work together to carry out digestion is called the digestive system. Food is digested in the digestive system and the nutrients are then absorbed and transported by the circulatory system to the cells of the body.

There are four main steps in digestion: ingestion (the taking in of nutrients), digestion (the physical and chemical breakdown of complex food molecules into smaller molecules), absorption (the transfer of digested nutrients from the digestive system to the bloodstream), and egestion (the removal of waste food materials from the body).

Specialized Digestive Systems

Each animal species has unique adaptations that enable it to obtain and digest food. The mosquito, for example, has specialized mouth structures and a digestive system that may be used for sucking blood to obtain nutrients (**Figure 1**). Regardless of diet, most animals have digestive systems with specialized features that enable them to break down food into usable nutrients.

Some simple animals, such as flatworms or jellyfish, have a digestive sac with a single opening into a **gastrovascular cavity**. This opening serves both as an entrance for food and as an exit for waste materials. In some cases, the opening to the gastrovascular cavity is surrounded by tentacles that are used to capture prey (**Figure 2**). Food is taken directly into the gastrovascular cavity and is broken down by chemicals that are released into the cavity. The nutrients are then absorbed by the cells that line the gastrovascular cavity, and digestion continues inside the cells. Nutrients diffuse from these cells to all other cells of the body.

More complex animals digest food along a digestive tract that has two openings—one for food intake and another for waste elimination. The digestive tract is organized into specialized regions that enable the breakdown and absorption of food as food moves along the tract in one direction. This design is often referred to as a complete digestive system.

One example of an animal with a complete digestive system is the earthworm (**Figure 3**). In the earthworm, food ingested through the mouth travels through the muscular pharynx and into the esophagus. The esophagus then pushes the food into the crop for temporary storage. From there, physical breakdown of the food is carried out by a muscular organ called the gizzard. The food particles then pass into the intestine where they are further broken down into smaller molecules. These small molecules can then be absorbed by the cells lining the intestine and any undigested wastes eliminated through the anus.

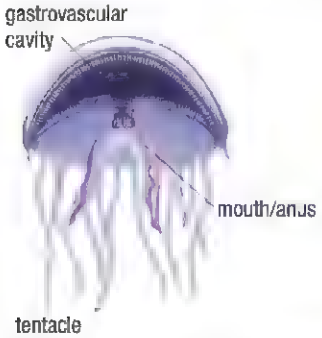

Figure 2 Jellyfish have a single opening through which food is taken in and waste is expelled.

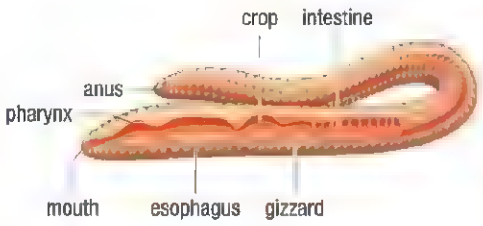

Figure 3 An earthworm's digestive system consists of a mouth, a pharynx, an esophagus, a crop, a gizzard, and an intestine.

The Structure of the Human Digestive System

The human digestive system is also a complete digestive system. Unlike that of the earthworm, the digestive tract of humans is much longer than the body (**Figure 4**). Often referred to as the **gastrointestinal tract (GI tract)**, the human digestive tract is approximately 7 m to 9 m long, depending on the age and size of the individual.

gastrointestinal tract (GI tract) the passageway or tube that extends from the mouth to the anus and in which the process of digestion takes place

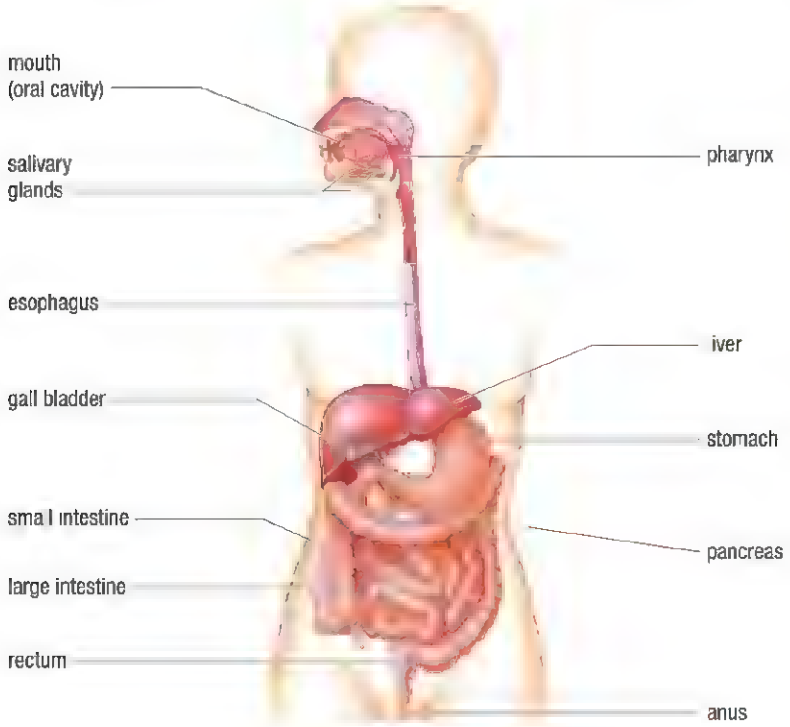

Figure 4 The human digestive system and accessory organs

Investigation 11.1.1

Fetal Pig Dissection (p. 510)
Make note of the location of the various organs in the human digestive system. At the end of this unit, you will have an opportunity to dissect a fetal pig and examine the structure of the digestive system.

Every organ system in the human body depends on the digestive system for nutrients, but the digestive system also depends on other organ systems. Muscle and bones, for example, enable animals to catch and ingest food. The circulatory system transports oxygen and other materials to the digestive organs, and carries digested foods from the digestive system to the tissues of the body. The nervous system and endocrine system regulate the actions of the digestive organs. Digestion involves interaction among several body systems.

9.3 Summary

- The digestive systems of animals vary depending on several factors, including the size, complexity, and diet of the organism.
- The human digestive system is a complete digestive system and has four major functions: ingestion, digestion, absorption, and egestion.

9.3 Questions

1. Explain the basic functions of the digestive system. K/U
2. Use a T-chart or diagrams to compare the differences between a gastrovascular cavity and a complete digestive system. K/U T/I C
3. Suggest possible advantages of a digestive system with two openings over a system with only one opening. K/U T/I A
4. Explain how the digestive system depends on other organ systems, such as the circulatory system. K/U A
5. Research the digestive system of an organism of your choosing. How is the digestive system for your chosen organism similar to and different from the human digestive system? K/U T/I A

GO TO NELSON SCIENCE

9.4 Digestion in the Mouth and Stomach

Imagine working on a reverse assembly line. Instead of putting parts together to create something, the task is to break an object down into its component parts. The digestive system is similar to this "disassembly line." Various specialized locations along the gastrointestinal tract work to break food down physically and chemically. In this section, we will look at the digestive processes that take place in the mouth and stomach. You will learn about the rest of the gastrointestinal tract, specifically the intestines, in the next section.

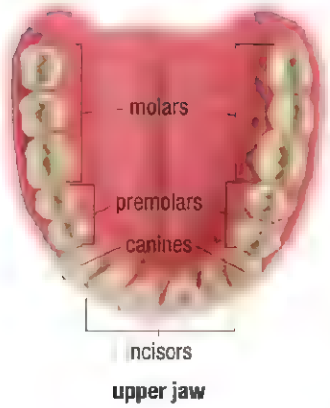

Figure 1 Human teeth are specialized for certain functions.

enzyme any chemical produced by cells that facilitates biochemical reactions in the body, such as those involved in digestion and metabolism; all enzymes are proteins

amylase an enzyme that breaks down complex carbohydrates

mucus a protective secretion produced by the epithelial cells that form the mucous membrane

LEARNING TIP

Secrete and Secretion

The word "secrete" means to produce and release a chemical substance from a cell or a gland.

The word "secretion" refers to the process of secreting, but can also refer to the substance that is produced. Secretions usually have a specific function.

Physical and Chemical Digestion in the Mouth

In humans, digestion begins in the mouth. Food is broken down into smaller pieces by the teeth (physical digestion). Teeth in the front of your mouth, called incisors and canines, are specialized for grabbing and cutting your food. Behind these teeth are premolars and molars—broad flattened teeth specialized for grinding and crushing food (**Figure 1**). The type of teeth an animal has is directly related to its diet. For example, mammalian herbivores have many molars for chewing plant matter, whereas mammalian carnivores have canine teeth that allow them to grab and kill prey.

The presence of food in the mouth and, often, simply the sight or smell of food, triggers the salivary glands to secrete a watery fluid called saliva. Saliva contains **enzymes**—chemicals that increase the rate of chemical reactions in living things. One enzyme found in saliva is **amylase**, which breaks down starch into smaller disaccharides (chemical digestion). Saliva also dissolves food particles, making it possible for you to taste food. Saliva contains **mucus**, a protective secretion that acts as a lubricant and aids in swallowing. On average, you produce 0.75 L to 1.5 L of saliva per day. Most of this saliva is water, which moistens the food into a ball, or *bolus*, so that it can be swallowed.

Once food has been chewed and mixed with saliva in the mouth, the tongue pushes it to the back of the mouth where it is swallowed (**Figure 2(a)**). As the food is pushed into the pharynx, the soft palate is raised to prevent food from entering the nasal passages. At the same time, the larynx is raised against a flap of soft tissue called the epiglottis. This covers the entrance to the trachea to prevent food from entering the lungs (**Figure 2(b)**). (If you place your finger on the outside of your neck over your larynx as you swallow, you will feel the larynx rise.) This process of taking food into the body through the mouth (by swallowing) is called ingestion.

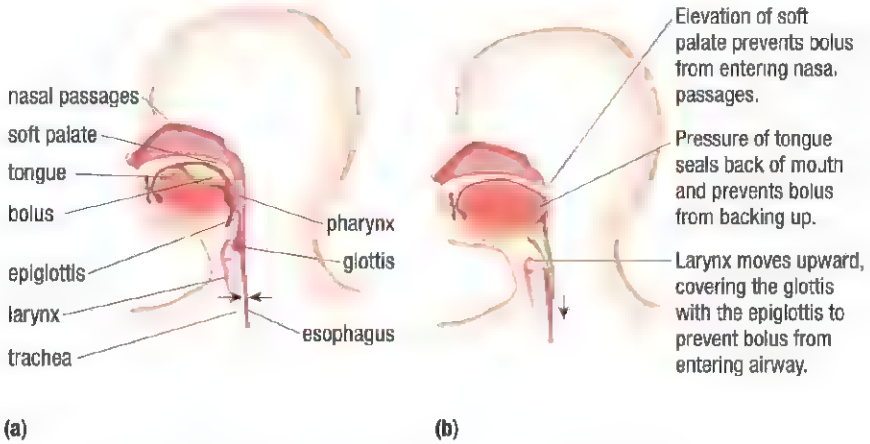

Figure 2 (a) Structures of the mouth, pharynx, and esophagus involved in the swallowing reflex (b) Motions that seal the nasal passages, mouth, and trachea during the swallowing reflex

Once swallowed, food moves from the mouth to the stomach by way of the esophagus. The **esophagus** is a long, muscular tube that carries food from the pharynx to the stomach. The food stretches the walls of the esophagus, activating the smooth muscles to undergo rhythmic, wave-like contractions called **peristalsis** (**Figure 3**). Peristalsis ensures the movement of food down the esophagus and into the stomach. It takes about 8 s for food to travel down the esophagus into the stomach. Although gravity helps, it is peristalsis that ensures the movement of food down through the esophagus to the stomach and through the entire digestive system. If you were to stand on your head, you would still be able to swallow liquids!

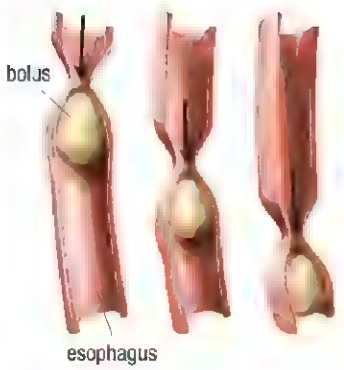

Figure 3 Peristalsis ensures that food is kept moving through the digestive system.

esophagus an organ consisting of a muscular tube that passes food from the pharynx to the stomach

peristalsis the rhythmic, involuntary wave-like contractions of the smooth muscles of the gastrointestinal tract

sphincter the circular muscle that contracts to close an opening in the body

The Structure of the Stomach

The stomach is a J-shaped, muscular organ that continues the mechanical and chemical digestion that started in the mouth. The stomach can expand in size to store up to 2 L of food. Proteins are partly digested in the stomach and continue digesting in the small intestine. Lipids and carbohydrates are not digested in the stomach.

The movement of food into and out of the stomach is controlled by circular muscles called **sphincters**. There are more than 50 sphincters in the human body, and several of these are in the digestive tract. The gastroesophageal sphincter is located where the esophagus joins the stomach (**Figure 4**). When relaxed, the gastroesophageal sphincter allows food to enter the stomach. When contracted, it prevents food from moving back into the esophagus.

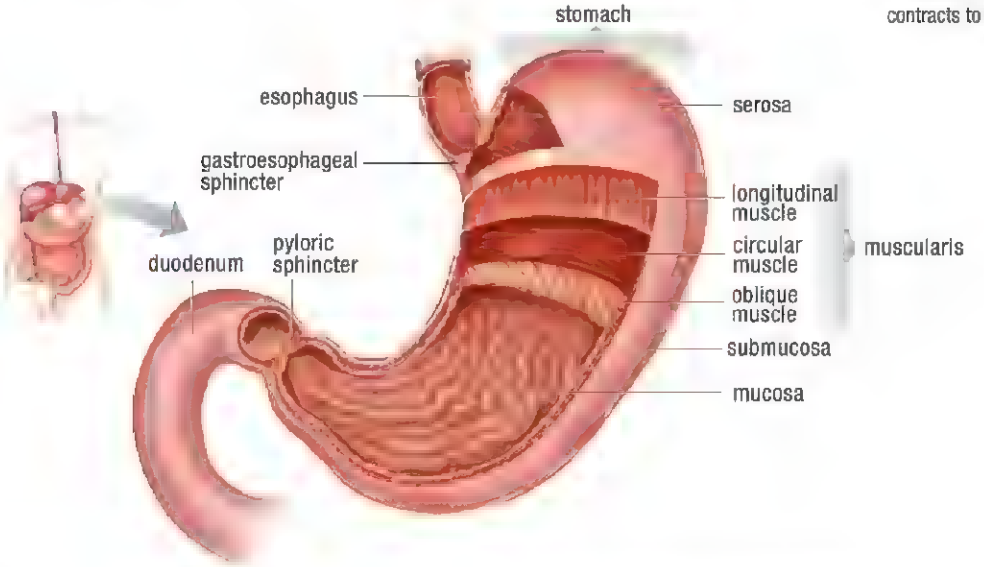

Figure 4 The stomach is a muscular, J-shaped organ. A sphincter muscle at either end controls the movement of food in and out of the stomach.

The stomach has four layers, each of which has a special structure and function (Figure 4). The innermost layer is an extensively folded layer called the mucosa. The mucosa secretes gastric juice, which is a mixture of digestive enzymes, acid, and mucus. The epithelial cells in the mucosa divide rapidly to heal any damage. In fact, the entire stomach lining is replaced about every three days! The next layer is the submucosa—a layer of connective tissue that contains networks of nerves and blood vessels. The third layer, called the muscularis, or muscle layer, consists of smooth muscles. These muscles contract frequently, churning and mixing the food with gastric juices to produce a semi-liquid material called **chyme**. The smooth, outermost layer of the stomach, called the serosa, holds the stomach in place and secretes a lubricating fluid that eliminates friction between organs.

chyme a semi-liquid mixture of food and gastric juice

Chemical Digestion in the Stomach

gastrin a hormone that stimulates the release of hydrochloric acid and pepsinogen in the stomach

The process of digestion is a carefully controlled and coordinated process that involves enzymes, hormones, and nerves. The nerves in the submucosa detect when food is present and initiate the release of a hormone called gastrin. **Gastrin** is released into the bloodstream and transported to gastric cells in the stomach, where it stimulates the release of gastric juice. Each gastric gland secretes only a tiny amount of gastric juice, but since there are millions of glands, the total amount of gastric juice produced is up to 2 L per day. Gastric juice is mostly made up of mucus, but also contains acid and digestive enzymes. The mucus, a slippery secretion, coats and protects the lining of the stomach from acid and digestive enzymes.

The acid present in gastric juice is very strong; it normally ranges from pH 2.0 to pH 3.0. In comparison, lemon juice is pH 2.4 and battery acid is pH 1.0. The acidic gastric juice kills many harmful micro-organisms that are ingested with food. It stops the action of amylase but provides the necessary pH for the activation of other digestive enzymes, such as pepsinogen. The hydrochloric acid present in gastric juice converts pepsinogen to its active form, **pepsin**, which begins the breakdown of proteins into separate amino acids. Secreting the inactive enzyme pepsinogen is a safety mechanism that prevents damage to the stomach tissue. If gastric glands were to make pepsin instead of pepsinogen, the stomach would digest itself.

pepsin a protein-digesting enzyme produced in the stomach

Nerve endings in the lining of the stomach are stimulated when food enters the stomach and stretches the lining walls. When this happens, the nerves release signals that cause an increase in muscular contractions, which mixes the food with gastric juice.

Acid Reflux

If the gastroesophageal sphincter does not close completely, acid from the stomach can enter the esophagus. This causes a burning sensation in the lower throat that we know as heartburn, or acid reflux. An overfilled stomach can force some of the acidic stomach contents back up into the esophagus. Smoking can also be a significant contributing factor because it relaxes the gastroesophageal sphincter and stimulates acid production in the stomach.

Stomach Ulcers

ulcer a lesion or open sore on the epithelium of an organ

Stomach acid is strong enough to kill most bacteria that enter the stomach. However, one species of bacteria, *Helicobacter pylori* (commonly known as *H. pylori*), is able to survive by secreting acid-neutralizing enzymes and by burrowing through the mucosa. These bacteria prevent mucus-producing cells from producing enough mucus to protect the stomach lining. When the lining is exposed to the strong stomach acid, an open sore, called an **ulcer**, can develop (**Figure 5**). Ulcers can bleed and can be quite painful. Bleeding ulcers can also be quite dangerous because the bacteria can enter the bloodstream and produce an infection throughout the body.

Figure 5 A break in the mucosal layer can result in an ulcer.

H. pylori may be transmitted through food or water, but the bacteria have also been found in the saliva of people with ulcers. *H. pylori* is usually successfully eliminated with antibiotics.

CAREER LINK

Gastroenterologist

To learn more about becoming a gastroenterologist,

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A CURE FOR ULCERS

Until the 1980s, the medical community believed that ulcers were caused by stress and diet. Dr. Robin Warren, an Australian doctor, was puzzled by the discovery of bacteria (later named *Helicobacter pylori*) in the stomachs of patients who were suffering from ulcers. A colleague of Dr. Warren's, Dr. Barry Marshall, was fascinated by this discovery and decided to conduct further research. He was convinced that there was a connection between the bacteria and ulcers. To test this connection, he drank a solution containing *H. pylori* bacteria and developed the same symptoms exhibited by ulcer patients. This earned him the nickname "the guinea pig doctor." He successfully treated himself with antibiotics.

Dr. Marshall presented his ideas at medical conferences and in publications. Unfortunately, the established ideas about the causes and treatments for ulcers and other stomach ailments were very resistant to change. Looking back on his fight to have his research accepted, Dr. Marshall said, "To gastroenterologists, the concept of a germ causing ulcers was like saying that the Earth is flat." When he challenged the medical community to prove him wrong, experiments designed to refute his hypothesis actually confirmed it. By the mid 1990s, Dr. Marshall's persistence paid off and his hypothesis was generally accepted. Dr. Marshall and Dr. Warren were awarded the Nobel Prize in Medicine in 2005 (**Figure 6**). Antibiotic treatment of most ulcers is now the standard practice worldwide.

Figure 6 Dr. Robin Warren, left, and Dr. Barry Marshall, nicknamed "the guinea pig doctor," changed our understanding of the causes and treatments of ulcers.

9.4 Summary

- The act of swallowing moves the chewed food from the mouth, through the esophagus, where wave-like contractions, called peristalsis, move the food to the stomach.
- The process of digestion starts in the mouth, with the physical breakdown of food by the teeth. Chemical digestion also starts in the mouth, with the action of amylase, an enzyme found in saliva.
- The stomach is an organ where food is temporarily stored and chemical digestion continues.
- Gastric juice provides the necessary acidic environment for enzymes to function. It also kills most of the bacteria or other micro-organisms that enter the stomach.
- Mucus present in gastric juice helps protect the stomach from acid damage.
- Gastrin is the major hormone that regulates acid secretion in the stomach.
- Pepsinogen is secreted in the stomach and is converted to pepsin, a protein-digesting enzyme, when exposed to the acid present in gastric juice.
- An ulcer is an open sore in the lining of the stomach caused by the presence of *H. pylori* bacteria in the stomach.

9.4 Questions

1. The trachea and the esophagus are located side by side. What mechanisms prevent food from entering the trachea and the lungs when swallowing? K/U
2. Explain the mechanism that moves food through the gastrointestinal tract. K/U
3. What is the role of the stomach in digestion? Describe how the structure of the stomach relates to its function. K/U A
4. Strong acids can dissolve or chemically burn living matter. Why is the stomach tissue not damaged by stomach acid? Describe the mechanism by which the stomach lining is protected from the very acidic gastric juice. K/U A
5. Pepsinogen is sometimes referred to as a pre-enzyme because it is the inactive form of the enzyme pepsin. Why is it necessary to have a pre-enzyme? K/U A
6. A cheaper but tougher cut of steak can be made more enjoyable by the process of "tenderizing." Use the Internet and other sources to find methods of tenderizing meat. T/I A
   (a) Explain the process of meat tenderizing.
   (b) What are the natural sources of chemical tenderizers?
   (c) How is the process of meat tenderizing similar to digestion?
7. (a) What does the Marshall/Warren story tell us about the nature of science?
   (b) Why might the medical or scientific community be reluctant to accept new ideas? K/U A
8. Use the Internet and other sources to research stomach stapling and gastric banding. Write a brief report explaining why these procedures are used, how they work, and what the associated risks and benefits are. T/I C
9. Ruminants are mammals that have a specialized stomach adapted for digesting plant material. Use the Internet and other sources to find information to help you answer the following questions: K/U T/I C
   (a) Give three examples of ruminant animals.
   (b) Name the four compartments of the stomach of ruminants. Briefly explain the function of each.
   (c) How is the specialized stomach of the ruminant adapted to digesting plant material?
   (d) What does the word *ruminate* mean in everyday language?

GO TO NELSON SCIENCE

9.5 Digestion in the Small and Large Intestines

Do some foods keep you feeling full for a long time? Do you ever feel that after eating certain foods, you are hungry again in a short time? Some foods stay in the stomach longer than others and keep you feeling full. Other foods move quickly from the stomach to the small intestine. Carbohydrates, proteins, and lipids are digested in the small intestine with the help of hormones and enzymes. About 3 h to 5 h are required to process the contents of a meal in the small intestine, where nutrients from digested food are absorbed into the body.

Mini Investigation

Explore Surface Area

Skills: Observing, Analyzing, Communicating SKILLS HANDBOOK A2.1, A6.2

Many biological processes occur on, or through, the surfaces of cells and tissues. The amount of available surface area determines how efficiently these processes occur. The digestive system (as well as other organ systems) requires large surface areas in order to function efficiently. In this activity, you will examine a model that increases surface area in a limited space.

Equipment and Materials: 10 cm × 10 cm piece of corrugated cardboard (**Figure 1**); ruler

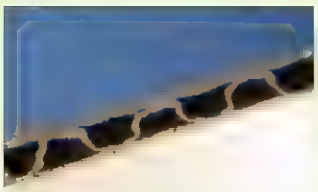


Figure 1 Corrugated cardboard

1. Measure and record the length and width of the top layer of the piece of corrugated cardboard. Use your measurements to calculate the area of the top layer.
2. Calculate the surface area of the piece of cardboard. Ignore the thickness of the cardboard.
3. Separate the three layers of the cardboard, taking care not to tear the layers.
4. Flatten the folded (corrugated) middle layer. Measure and record its dimensions, and calculate its total surface area.

A. What is the difference between the surface area you calculated in Step 2 and the surface area you calculated in Step 4? What accounts for this difference in area? T/I

B. By what percentage is the surface area of the middle layer greater than the surface area of the cardboard in Step 2 (before it was separated)? T/I

C. Suggest at least one method of further increasing the surface area within the same space as the original piece of cardboard. Illustrate your suggestions with a simple sketch. T/I C A

LEARNING TIP

Surface Area
Surface area is the sum of the exposed area of an object. For example, the surface area of a piece of paper would be the sum of the areas of the front and back of the paper.

The Structure of the Small Intestine

Most digestion and absorption of nutrients takes place in the small intestine. The small intestine is a long tube that is only about 2.5 cm in diameter. Although narrow, this section of the GI tract can be up to 7 m in length. In comparison, the large intestine can be up to 7.6 cm in diameter but is only about 1.5 m in length. Lipids and carbohydrates, as well as any remaining proteins, are digested in the small intestine.

The small intestine is made up of three sections: the duodenum, the jejunum, and the ileum (**Figure 2**). The duodenum is the first 25 cm to 30 cm of the small intestine and is where most enzymes are added and digestion in the small intestine begins. In the jejunum, digestion continues and some nutrients are absorbed. However, the majority of nutrients are absorbed in the ileum, the last section of the small intestine. There is no clear division between the jejunum and the ileum, but they can be distinguished by the shapes of the cells in the epithelium.

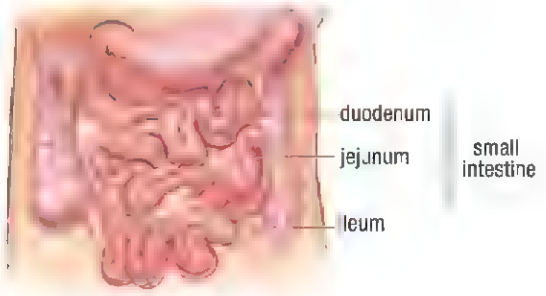


Figure 2 The three segments of the small intestine

The inner surface of the small intestine is adapted to provide the maximum surface area for efficient nutrient absorption. The inner layer of the small intestine is folded into ridges and has many small finger-like projections called **villi** (singular: villus) which produce an estimated tenfold increase in surface area. To further increase the surface area available for absorption, each of the epithelial cells that make up the villi has even smaller, microscopic projections of the cell membrane called **microvilli** (singular: microvillus) (**Figure 3**). The combined effect of the villi and microvilli is estimated to increase the surface area by a factor of 500. Within each villus is a network of tiny blood vessels called capillaries. Capillaries are part of the circulatory system, which you will learn more about in Chapter 11. All nutrients, except digested fats, enter the bloodstream through the capillaries. Digested fats are transported through small vessels called **lacteals**. The digested fats are transported into the lymphatic system, and from there into the bloodstream.

villus a small, finger-like projection of the small intestine mucosa

microvillus a microscopic projection of the cell membrane of certain types of epithelial cells; greatly increases the surface area of the cell

lacteal a lymphatic vessel within a villus, through which digested fats enter the circulatory system

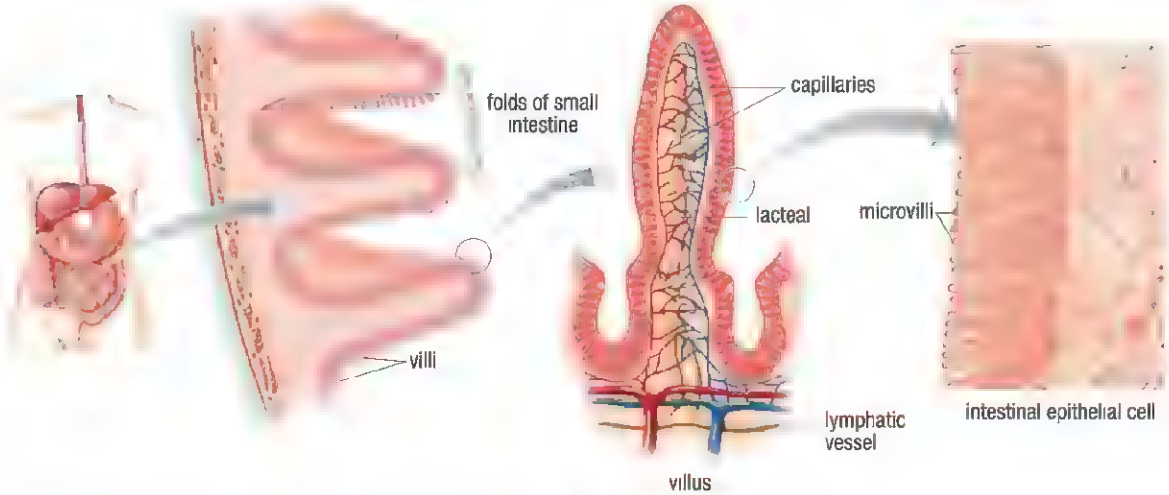


Figure 3 The villi and microvilli greatly increase the surface area available for absorption of nutrients.

Chemical Digestion in the Small Intestine

The pyloric sphincter controls the passage of food from the stomach into the small intestine. When the food in the stomach has been mixed with gastric juice and the proteins are partially digested, the pyloric sphincter periodically relaxes to release small portions of chyme into the duodenum (**Figure 4**). This slow and steady release of chyme into the small intestine prevents overloading and allows time for thorough digestion.

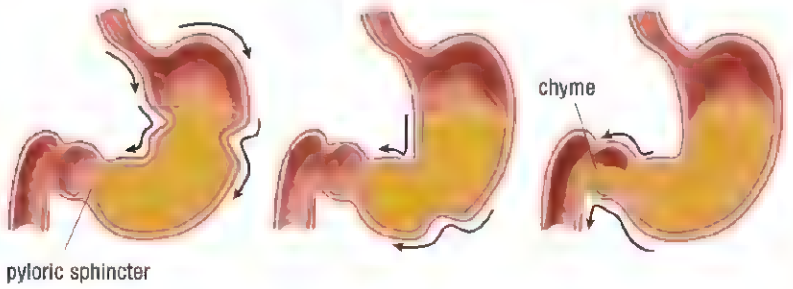


Figure 4 The pyloric sphincter controls the movement of the chyme from the stomach to the duodenum.

Most of the enzymes required for digestion are added in the duodenum. This digestion requires input from the pancreas, liver, and gall bladder.

Investigation 9.5.1

Factors Affecting the Digestion of Starch (page 426)

Consider what you have read about lipid, carbohydrate, and protein digestion. At the end of this section, you can complete Investigation 9.5.1.

In this controlled experiment you will identify factors that affect the digestion of starch. You will conduct an experiment to determine how digestion is affected by these factors.

The Role of the Pancreas in Digestion

The pancreas is a long, flat gland nestled between the stomach and the duodenum. The pancreas has a dual role. It secretes enzymes that are critical to the digestive process, and it also secretes hormones that regulate the absorption and storage of glucose from the blood. (This second function of the pancreas will be addressed in Chapter 11.)

The digestion of carbohydrates that began in the mouth continues in the duodenum. The enzyme amylase, found in saliva, is also secreted by the pancreas. This amylase continues the digestion of starch that was started in the saliva.

When fat-rich chyme enters the duodenum, a hormone called cholecystokinin (CCK) is secreted by special cells in the mucosa of the duodenum and released into the bloodstream. This hormone signals the pancreas to secrete a variety of substances, including ones that control the pH of the intestine and enzymes that are needed for lipid, carbohydrate, and protein digestion. These secretions enter the duodenum through the pancreatic duct (**Figure 5**). CCK also signals the stomach to slow down the speed of digestion so that the small intestine can effectively digest the fats.

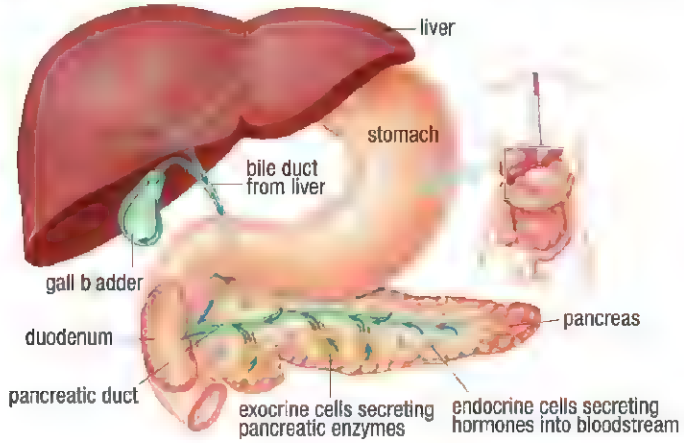


Figure 5 The digestive enzymes, hormones, bile, and other substances secreted by the liver and pancreas enter the duodenum.

The chyme that enters the small intestine has a low pH of about 2.5. When the acidic chyme enters the small intestine, a chemical called prosecretin that is present in the epithelial cells of the small intestine is converted into its active form, secretin. **Secretin** is a hormone that stimulates the liver to make more bile and encourages the pancreas to secrete lipid and protein enzymes. However, its primary function is to stimulate the pancreas to release bicarbonate ions (HCO_3^-) to neutralize the acidic chyme and raise the pH from about pH 2.5 to pH 9.0. Pepsin is inactivated in the basic pH conditions since it requires an acid environment to be activated. Thus, secretin protects the small intestine from stomach acids. Secretin also acts as a digestive rate regulator and prevents more food from entering the duodenum from the stomach until the current batch is digested.

secretin a hormone secreted by the duodenum that stimulates pancreatic and bile secretions

Since pepsin is active only in acidic conditions, the action of pepsin is discontinued in the small intestine. However, protein digestion is carried on by other enzymes. The pancreas releases trypsinogen, which is an inactive form of a protein-digesting enzyme called **trypsin**. The trypsinogen travels from the pancreas to the duodenum. Once it reaches the duodenum, an enzyme called **enterokinase** converts it into active trypsin. Trypsin continues the work begun by pepsin in the stomach, further breaking down any partially digested proteins that remain. Other protein-digesting enzymes help break the short protein chains into single amino acid molecules. **Figure 6** shows the breakdown of proteins in the small intestine.

trypsin a protein-digesting enzyme produced from trypsinogen

enterokinase an enzyme of the small intestine that converts inactive trypsinogen into trypsin

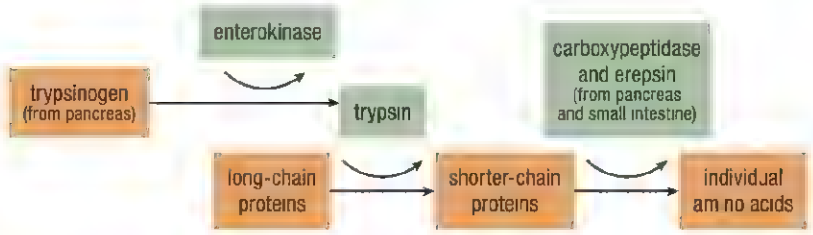


Figure 6 The breakdown of proteins into amino acids occurs in the small intestine.

Mini Investigation

Chemical Reactions with Fruit Juice!

Skills: Controlling Variables, Performing, Observing, Analyzing

SKILLS HANDBOOK A1.2, A2.1

Many foods contain chemicals that can break down other foods in a way that is similar to the action of chemicals in the digestive system. In this activity you will test a number of fruits for evidence that they contain these "digestive chemicals."

Equipment and Materials: 6 test tubes; dissolved gelatin; juices of fresh fruits (apple, orange, kiwi, pineapple, papaya)

1. Number the test tubes 1 to 6.
2. Add 5 mL of water to test tube 1.
3. Add 5 mL of a different juice to each of test tubes 2 to 6. Record which juice has been added to each test tube.
4. Add 10 mL of dissolved gelatin to each of the test tubes and swirl or shake gently to mix the contents.
5. Place the test tubes in the refrigerator and leave overnight.
6. Prepare a table in which to record your observations.
7. Observe the contents of each test tube and describe any changes that have occurred. Record your observations in the table.

A. What is the control in this activity? T/I A

B. What evidence is there that a reaction has occurred in the test tubes? In which test tubes has the reaction occurred? T/I A

C. Based on your observations, which of the fruit juices contain chemicals that can break down other foods? T/I A

D. Gelatin is made of protein. Based on your current knowledge, propose an explanation for your observations. T/I A

E. How does this investigation relate to the functioning of the digestive system? K/U T/I A

F. Since gelatin and muscle meat are both made of protein, suggest a practical application for the fruit juices that contain the "digestive chemicals." T/I A

lipase an enzyme that digests lipids

Lipids are also digested in the small intestine. Fats that enter the duodenum are subjected to the action of **lipases**, a group of enzymes secreted by the pancreas that break down lipids. Lipases break the lipid chains into shorter chains and into individual fatty acid molecules. However, fats in chyme are present as large globules. Lipases cannot penetrate beyond the surface of the fat globules, so for lipases to efficiently digest lipids, the liver and its secretions must become involved.

The Liver and Gall Bladder

The liver is the largest internal organ of the body, located just underneath the diaphragm (refer back to Figure 5, page 414). The liver performs a number of important functions. In its digestive function, it is considered a gland because it produces and secretes bile. **Bile** emulsifies fats, breaking them into tiny droplets called micelles. Once the large fat globules are broken down into micelles, the lipases have a much greater surface area on which to act, and the rate of lipid digestion increases.

bile a substance that emulsifies fats for faster breakdown by lipases; produced by the liver

Bile is continuously produced in the liver, but it is stored in the gall bladder until food enters the duodenum. Lipids entering the duodenum stimulate the gall bladder to contract, which causes bile to be squeezed out from the gall bladder into the duodenum through the bile duct.

All blood travelling through the capillary beds of the intestines goes directly to the liver before returning to the heart. The liver begins the removal and breakdown of toxins, such as alcohol, that have been absorbed by the digestive system. The liver is also involved in producing and storing various nutrients including glycogen and fat-soluble vitamins. Due to its varied functions, there are many diseases and disorders that are associated with a malfunctioning liver, including various forms of hepatitis, jaundice, and cancer.

Absorption in the Small Intestine

Once proteins, carbohydrates, and lipids are broken down, they are absorbed in the jejunum and ileum. Vitamins, minerals, and water are also absorbed in the small intestine. The structure of the small intestine plays a very important role in absorption. Both the villi and microvilli increase the surface area for absorption of nutrients. Nutrients pass through these cells, into the bloodstream, where they are then transported by capillaries to the tissues of the body. There are several different mechanisms for absorption in the small intestine. These mechanisms can be categorized as either passive transport or active transport.

Passive Transport

passive transport the movement of materials across a cell membrane without any expenditure of the cell's energy

Passive transport is the movement of materials across a cell membrane without the use of energy from the cell. This includes (simple) diffusion, osmosis, and facilitated diffusion.

Due to their constant, random motion, particles in a gas or liquid state will spread out until all the particles are evenly distributed. This process is referred to as diffusion. Diffusion will follow the **concentration gradient**, from an area of higher concentration to an area of lower concentration (**Figure 7(a)**, next page). Many nutrients enter the cells lining the small intestine by simple diffusion. For example, small amino acids can diffuse directly into the bloodstream.

concentration gradient the difference in the number of molecules or ions of a substance in a given volume between adjoining areas

Osmosis is the diffusion of water molecules across a selectively permeable membrane, from an area of higher concentration (of water molecules) to an area of lower concentration. Some of the water content in food is absorbed by osmosis in the stomach and small intestine during digestion.

Another type of diffusion that plays a role in digestion is facilitated diffusion. **Facilitated diffusion** is the diffusion of molecules across a membrane through transport proteins. The transport proteins are embedded in the cell membrane and help, or facilitate, diffusion (**Figure 7(b)**). Transport proteins physically bind to molecules on one side of the membrane and release them on the other side. Each transport protein has a unique size and shape that allows only certain substances to pass through. Transport proteins act as gateways that increase the rate of diffusion of specific nutrient molecules. For example, during digestion, carbohydrates are broken down into disaccharides and monosaccharides. Many of these carbohydrates are transported into the cells lining the small intestine by facilitated diffusion.

facilitated diffusion the diffusion of molecules across a cell membrane via a transport protein

Active Transport

In **active transport**, materials are moved across a cell membrane, from an area of lower concentration to an area of higher concentration, using energy provided by the cell. As in facilitated diffusion, special transport proteins embedded in the cell membrane actively move materials through the membrane (**Figure 7(c)**). Unlike facilitated diffusion, this movement across the cell membrane requires energy from the cell. Active transport is used to transport molecules that are too large to diffuse through the cell membrane on their own, as well as to transport molecules (or ions) that have a strong and uneven electrical charge that prevents diffusion across the membrane.

active transport the transportation of materials through a cell membrane using energy from the cell

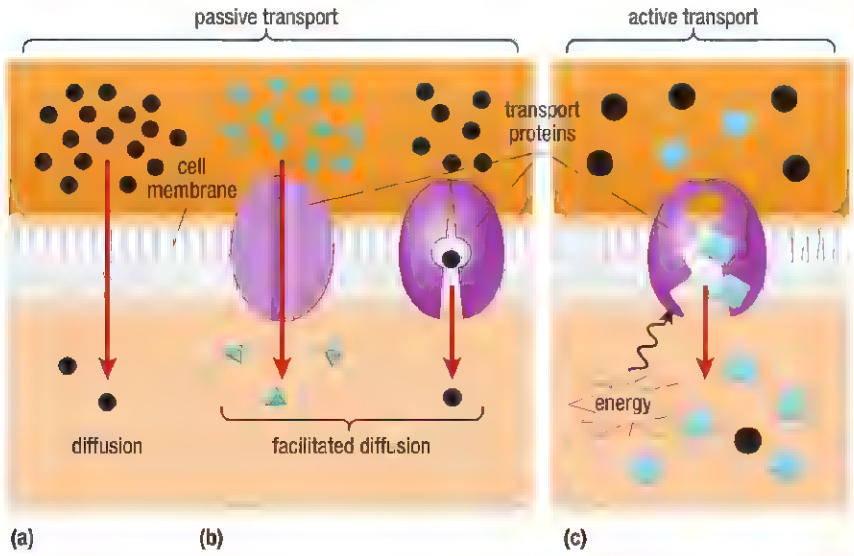


Figure 7 (a) In diffusion, substances move across the cell membrane from an area of higher concentration to an area of lower concentration. (b) In facilitated diffusion, transport proteins speed up the movement of molecules that already move across the cell membrane. (c) In active transport, energy is required to move molecules through transport proteins across the membrane. Only certain types of molecules can pass through the transport proteins.

Absorption of Nutrients in Capillary Networks

Whether transported by diffusion, osmosis, facilitated diffusion, or active transport, all nutrients make their way through the mucosa of the small intestine and into the capillary networks in the villi. These capillary networks carry nutrients through the bloodstream to the rest of the body. The lacteals, which are small vessels of the lymphatic system, carry dietary fats through the lymphatic system, eventually reaching the bloodstream. Nutrients are transported from the bloodstream into the body cells by means of passive or active transport.

The Structure and Function of the Large Intestine

The diameter of the large intestine, rather than the length, gives it its name. The large intestine is approximately 1.5 m in length but is two to three times larger in diameter than the small intestine, about 7.6 cm. The large intestine consists of the cecum, colon, rectum, and anus, or external opening (**Figure 8**).

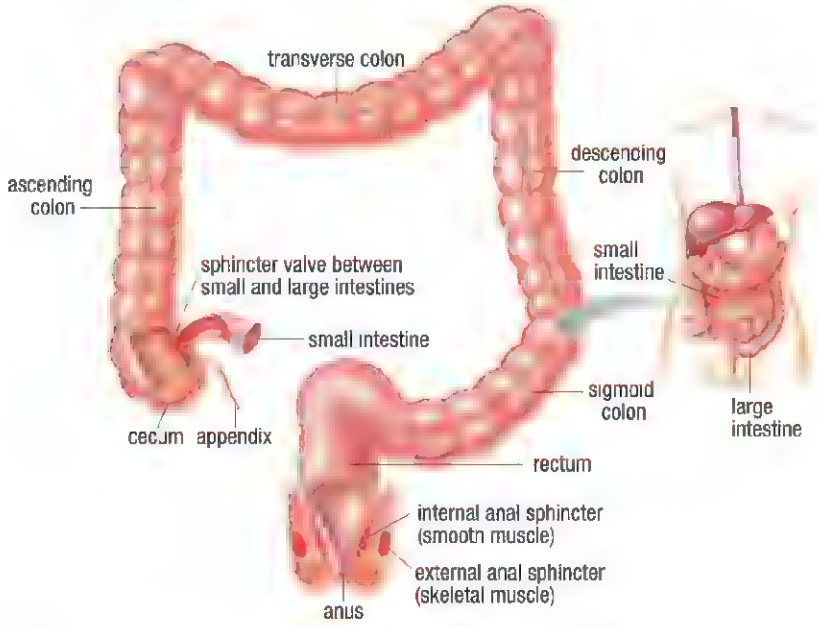


Figure 8 Digestion and most nutrient absorption are complete when food reaches the large intestine. Waste materials are collected here and are evacuated from the body through the anus.

cecum a blind pouch at the upper end of the large intestine

colon the longest part of the large intestine

rectum the lower 20 cm of the large intestine, generally referred to as the lower bowel, where feces are stored

anus the opening at the lower end of the large intestine through which digestive wastes are eliminated from the body

The small intestine does not simply continue on and become the large intestine. The small intestine joins the large intestine a few centimetres from the end. The short upper end of the large intestine creates a blind pouch called the **cecum**, a sort of dead end that receives the processed material from the small intestine. A small finger-like projection from the cecum is called the appendix. The appendix does not serve any digestive function in modern humans but may have had a digestive function in its evolutionary past.

The **colon** is the longest part of the large intestine and has four segments: the ascending colon, the transverse colon, the descending colon, and the sigmoid colon. The **rectum** is the last 20 cm of the large intestine. The rectum holds the waste products of digestion until they are eliminated through the external opening, the **anus**.

Digestion is complete and most of the nutrients have been absorbed by the time the digested material reaches the large intestine. However, there is still a significant quantity of undigested and indigestible material, such as cellulose, that cannot be broken down by humans. As this matter passes through the colon, most of the water is absorbed through the process of osmosis. Approximately 20 L of fluids pass through the large intestine daily, and most of this is absorbed back into the body. This fluid comes from the water ingested in the diet and from saliva, mucus, gastric juices, and other digestive fluids that are secreted as food moves through the GI tract. Vitamins B and K and sodium, Na^+, and chloride, Cl^-, ions are also absorbed. It may take 4 h to 72 h for the undigested material to pass through the large intestine, depending on the types and volume of food eaten.

There are more than 500 species of bacteria that normally inhabit the large intestine. Some of these species of bacteria are important partners in human nutrition. The most common species of bacteria in the human large intestine is *Escherichia coli*, or *E. coli*. These bacteria exist in the intestine in a mutually beneficial relationship. The bacteria live in a suitable environment and have access to a plentiful food supply. In return, they produce essential substances such as vitamin K and some B vitamins. Another byproduct of bacterial action is gas – a mixture of carbon dioxide, methane, and hydrogen sulphide. The amount of gas produced is affected by the types of food that are eaten. Most of the gas is absorbed in the intestine, but some may escape through the anus as flatulence.

Although these bacteria are needed, they can create serious or even fatal problems if they enter and reproduce in the stomach or small intestine. These problems will be explored in Section 9.6.

Egestion

The indigestible components of food, such as cellulose and other fibres, are important in the diet. They provide bulk and help maintain a full feeling for a longer time. This can reduce overeating and help maintain a healthy weight. Fibre also helps retain some water in the large intestine, which is important in **egestion**, the elimination of digestive wastes.

egestion the removal of waste food materials from the body

The absorption of water in the large intestine changes the liquid material in the colon into a soft solid called **feces**. If too much water is absorbed back into the bloodstream, the feces become firmer and constipation may be the result. If too little water is absorbed, watery feces, or diarrhea, may result, and this can lead to dehydration. The problem of diarrhea will be discussed in Section 9.6.

feces the undigested material that is eliminated as waste from the body

Nerves in the wall of the large intestine detect the movement of feces into the rectum. This initiates the defecation reflex, which causes the urge to have a bowel movement. While this is a reflex, there is some degree of control. The anus is surrounded by two sphincter muscles (Figure 8, page 418). The internal anal sphincter is a smooth muscle and therefore under involuntary control. The external anal sphincter is a skeletal muscle and under voluntary control. Feces are eliminated through the anus when both sphincters are relaxed.

Endoscopy: Looking Inside the Body

endoscopy any medical procedure that uses an endoscope to look inside the body

Historically, the only way to directly examine the digestive system was to perform surgery. Medical scientists and technologists have developed alternative methods of seeing inside the human body that are much safer and less traumatic for patients.

The endoscope is a tool that is designed to look inside the body. It consists of a narrow tube that is fitted with a light source, a lens, and a camera to obtain images (**Figure 9**). An endoscope has one or more openings through which tools can be inserted. This tube can be inserted through a natural opening in the body such as the mouth or anus, or through a small incision into the body cavity. The procedure that uses an endoscope to look inside the body is referred to as **endoscopy**.

Endoscopes can also be used to perform some medical procedures. Endoscopes are designed with remotely operated tools that can be inserted through the tube. For example, samples of tissue are often required for detailed examination under a microscope. The process of removing a tissue sample is called a biopsy. If a biopsy of the intestine is needed, a biopsy tool at the end of a cable is inserted through the endoscope tube and a tiny sample of the intestinal lining is removed.

Many surgeries can also be completed using endoscopes. For example, the removal of a diseased gall bladder is one of the most common surgical procedures that use endoscopes. Compared to open surgery, the procedure is less painful, has a shorter recovery period, requires a shorter hospital stay, and is more cost effective. About 98 % of all gall bladder removals are now done using endoscopes.

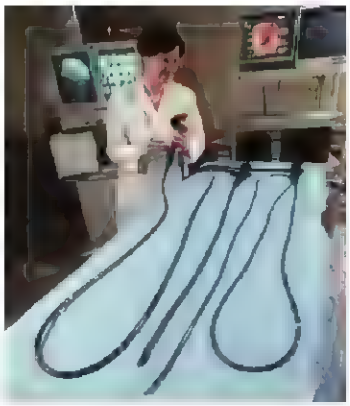


Figure 9 The flexible endoscope is a long tube that varies in diameter, depending on the area of the body to be explored. It includes a light source and a lens and camera to capture images

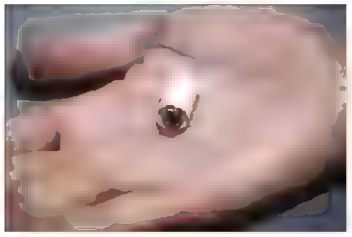


Figure 10 A capsule endoscope

The Capsule Endoscope

Although the traditional endoscope is a remarkable tool, it cannot be used to examine the entire length of the small intestine. The latest technology in gastrointestinal endoscopy is the capsule endoscope. Advances in miniature and wireless technology have enabled technologists to create a camera small enough to fit inside a capsule that can be swallowed (**Figure 10**). The capsule passes through the digestive tract, taking thousands of pictures that are transmitted wirelessly to a receiver.

There is tremendous potential for future advancements in capsule endoscopy. The capsules could be equipped with sensors, such as pH and temperature sensors, and might even be able to deliver drugs to specific targets within the digestive tract.

UNIT TASK BOOKMARK

Consider what you have learned about the structure and function of the human digestive system. How can this information help you in the Unit Task when you create a plan for a healthy diet?

9.5 Summary

- Most digestion takes place in the duodenum and the jejunum of the small intestine. Enzymes, hormones, and bile from the pancreas and the liver are secreted into the bloodstream or directly into the duodenum.
- The mucosa of the small intestine consists of villi and microvilli, which greatly increase the surface area for absorption.
- Absorption of nutrients occurs in the jejunum and ileum in the small intestine. Water, sodium, and chlorine ions, and some vitamins, are absorbed in the colon in the large intestine.
- Passive transport is the movement of materials across a cell membrane without the expenditure of energy by the cell. Passive transport includes diffusion, facilitated diffusion, and osmosis.
- Active transport uses the cell's own energy to move materials into or out of the cell.
- Indigestible material, such as cellulose, and other waste products are collected in the rectum and egested as feces through the anus.

9.5 Questions

1. Name the sections of the small intestine. Briefly describe the digestive processes that occur in each. K/U
2. (a) Describe the inside surface of the small intestine and explain the reason for this structure.
   (b) How does the structure of the small intestine relate to the Mini Investigation at the beginning of this section? K/U V
3. Explain the process that releases bile into the duodenum. K/U
4. Gallstones often develop in the gall bladder when minerals in the bile form into small pebble-like structures. This often requires the removal of the gall bladder. K/U T/I C A
   (a) What is the function of the gall bladder?
   (b) What might be the consequences of having your gall bladder removed?
   (c) Use the Internet and other sources to research how you might need to adjust your diet following gall bladder removal. Write a report of your findings.
5. Create a graphic organizer to summarize the physical and chemical digestion of the three groups of nutrients. K/U C
6. Name two hormones and two enzymes that are involved in digestion, and explain their roles. K/U
7. (a) Describe the processes involved in the breakdown of proteins into individual amino acids.
   (b) Why is it necessary to reduce large protein molecules to single amino acids? K/U V
8. How does facilitated diffusion differ from simple diffusion and osmosis? K/U
9. Use a graphic organizer to compare the roles of the small and large intestines in digestion K/U C
10. Ontario has implemented a colorectal cancer screening program. Use the Internet and other sources to find information about this program. T/I A
    (a) Describe the program and its goals.
    (b) What criteria are used to identify individuals who should have a colonoscopy?
    (c) Evaluate the use of colonoscopies in diagnosing and/or treating diseases such as colitis and colon cancer.
11. Unlike in humans, the cecum in some mammals is functional. Use the Internet and sources to research the structure and function of the cecum in rabbits. Write a brief report of your findings. T/I A

GO TO NELSON SCIENCE

Nausea, Vomiting, and Diarrhea

9.6

You have likely experienced nausea, vomiting, and diarrhea. Was it something you ate, or did you pick up some sort of bug? Whatever the cause, it was likely a very unpleasant experience! Although unpleasant, vomiting and diarrhea serve a useful function. They are two of the many strategies that the body uses to protect itself from disease-causing agents and foreign substances.

Nausea and Vomiting

The condition referred to as **nausea** is the unpleasant feeling that you are about to vomit. Your mouth may start to water and your stomach feel upset. You may break into a cold sweat and look rather pale. These feelings often, but not always, precede vomiting.

nausea the feelings associated with having the urge to vomit

Vomiting is a protective mechanism for removing toxins or foreign substances from the body. Vomiting, or **emesis**, is a strong muscular contraction that forces the contents of the stomach up through the esophagus and out through the mouth (and sometimes the nose). The prolonged, strong contractions of the diaphragm and tightening of the abdominal muscles force the stomach contents upward (**Figure 1**). At the same time, the gastroesophageal sphincter relaxes, allowing the contents of the stomach, now referred to as vomitus, to be expelled. During vomiting, breathing ceases as the larynx and epiglottis close the entrance to the trachea to prevent air or vomitus from entering the lungs.

emesis the expulsion of stomach contents through the esophagus and the mouth; also known as vomiting

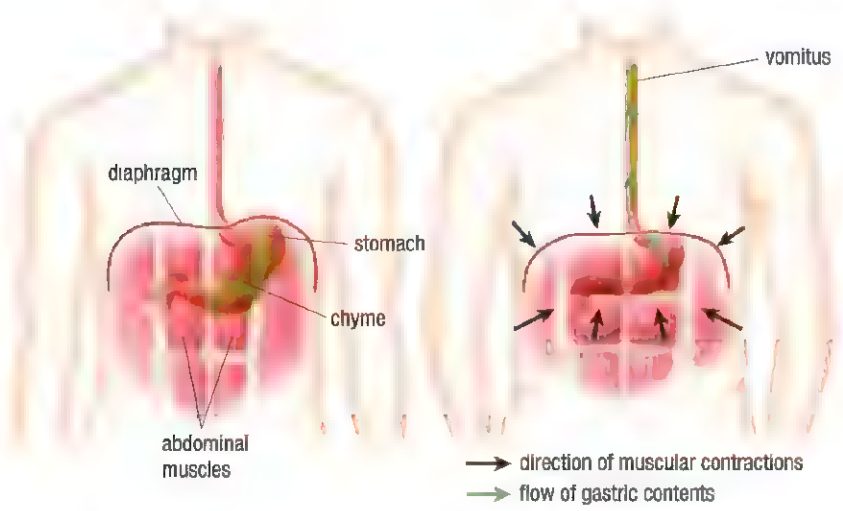


Figure 1 A strong contraction of the diaphragm and the abdominal muscles squeezes the stomach and forces its contents up through the esophagus and out of the body.

Causes of Vomiting

Nausea and vomiting are not disorders or diseases themselves; they are symptoms of some underlying condition. The signal for vomiting comes from the vomiting centre in the brain. This network of nerve cells receives stimuli from various parts of the body, such as the stomach, intestines, bloodstream, inner ear, or sensory organs. The stimuli may trigger the vomiting centre to initiate vomiting.

There are numerous conditions and diseases that can lead to nausea and vomiting (**Table 1**). The act of vomiting is the same regardless of the cause. Remember that vomiting is a symptom, not a disease itself. It is important to attempt to identify the underlying cause and treat the cause rather than the symptom.

Table 1 Causes of Nausea and Vomiting

Category of conditions	Examples
inner ear	• motion sickness • Ménière's disease
drugs	• chemotherapy • alcohol
infections	• bacterial, such as food or water poisoning • viral, such as stomach flu
brain	• meningitis • tumours
injury	• concussion • hemorrhage
diseases	• cancer • ulcers

Risks Associated with Vomiting

The main concern with vomiting is dehydration. If vomiting persists for more than a day and fluids cannot be held in the stomach, there is a risk of severe dehydration, and medical intervention may be required.

Another risk of vomiting is that some of the vomitus may enter the respiratory tract. The coughing reflex normally eliminates any material that enters the trachea, but if this reflex is impaired, by excessive alcohol consumption, for example, or if the vomitus is not completely cleared out of the trachea, then the individual may asphyxiate or develop an infection in the lungs because of the foreign matter.

Due to the forceful muscle contractions involved in vomiting, prolonged vomiting can result in tears in the lining of the esophagus or, less seriously, strains of the abdominal muscles.

Diarrhea

Most of the water in the food we eat and in the liquids we drink is absorbed in the colon. Water absorption forms the feces into a soft solid mass. If, for a variety of reasons, there is inadequate absorption, the feces are egested in a loose or watery form, which is a condition known as **diarrhea**. This is a very common condition, and the average person experiences diarrhea three or four times a year. Diarrhea is usually accompanied by other symptoms, such as an upset stomach, stomach pains, cramps, and intestinal gas.

diarrhea loose or watery feces

Causes and Risks of Diarrhea

Like vomiting, diarrhea is a protective mechanism. It is a way of flushing an infecting agent or foreign substance from the body. Some of the causes of vomiting are also commonly associated with diarrhea, but most cases of diarrhea are caused by some sort of infection. Common infecting agents include bacteria, viruses, and parasites. In many cases, bacteria, such as *Salmonella*, *Campylobacter*, or *E. coli*, enter the GI tract through contaminated food or water.

Figure 2 *E. coli* are found in the intestines of cows and other animals.

An *E. coli* infection is a very serious illness, especially for young children, the elderly, and individuals with existing health complications. Infections can trigger diarrhea, internal bleeding, and dehydration. In severe cases, it can result in kidney failure, which can be fatal if not properly treated. Other than ensuring that the infected person is properly hydrated and has proper nutrition, there is no specific treatment for *E. coli* infections. The infection usually runs its course in two to three weeks.

A highly publicized outbreak of *E. coli* infections occurred in Walkerton, Ontario, in May 2000. Walkerton's water supply became contaminated with an unusually virulent, or dangerous, strain of *E. coli* known as O157:H7, most commonly found in the gut of cows (**Figure 2**). Contaminated runoff from a nearby farm introduced the bacteria into the water supply. There were 1346 confirmed cases of *E. coli* infection, but it is estimated that more than 2000 individuals were infected. At least seven deaths were directly attributed to the infections.

Figure 3 Undercooked meat, especially ground beef, is a common cause of bacterial infections causing diarrhea.

Another similar food-borne illness caused by a bacterium is listeriosis. It is caused by the bacterium *Listeria monocytogenes*. These bacteria can be found in human and other animal feces, plants, and soil and can contaminate food products during food production, processing, or preparation. As in other food-borne illnesses, diarrhea is a common symptom. Although listeriosis is rarer than other diseases, it is more serious because severe cases are more likely to be fatal.

It is difficult to determine the number of cases of food-borne illnesses, because not all cases require hospitalization or a visit to a doctor. However, public health officials estimate that there are between 11 million and 13 million cases of food-borne illness in Canada annually. Food borne illnesses can be greatly reduced by proper hygiene and proper storage and cooking of meat, poultry, and seafood (**Figure 3**). It should be noted that both vomiting and diarrhea increase the likelihood that these disease-causing organisms will spread from one individual to another.

Research This

Diarrhea as a Cause of Death

Skills: Researching, Evaluating, Communicating

SKILLS HANDBOOK A2.1, A5.1

Despite the fact that most cases of diarrhea are easily and successfully treated, diarrhea kills about two million children worldwide each year—more than AIDS, malaria, and measles combined. It is second only to respiratory infections (mainly pneumonia) as the leading cause of death of children under five years of age.

1. Use the Internet and other sources to research the following:
   - the status of diarrhea-related illnesses in different regions of the world
   - the major causes of diarrhea
   - the recommended treatments and prevention
2. Summarize your findings in a one-page report.

A. In what regions of the world is diarrhea a significant problem? In which regions do most child deaths due to diarrhea occur? Provide statistics to support your answer. T/I

B. Why is diarrhea a significant cause of death in developing countries, more so than in developed countries? K/U T/I

C. The main treatment for diarrhea seems easy and very inexpensive. What factors do you think contribute to the lack of progress in preventing deaths from diarrhea? K/U A

D. Do you think of diarrhea as a cause of death in your community? Explain your thinking. C

GO TO NELSON SCIENCE

9.6 Summary

- Nausea is the feeling associated with the urge to vomit.
- One of the body's safety mechanisms for eliminating toxic or foreign substances is vomiting, or emesis, which is the emptying of the stomach contents through the mouth.
- Incomplete absorption of water in the colon results in watery feces, a condition known as diarrhea. Most cases of diarrhea are caused by infection.
- Both vomiting and diarrhea can result in health risks such as dehydration and other complications.

9.6 Questions

1. Using examples, explain the protective role of vomiting and diarrhea. K/U A
2. Describe the circumstances and the feelings during your last experience of nausea or vomiting. K/U A
3. Explain what takes place in the body during emesis, or vomiting. K/U
4. Pick one of the conditions in Table 1 (page 421) that could lead to vomiting. Use the Internet and other sources to research this condition. Prepare a brief report on the condition. Based on the information, assess the likelihood that vomiting will be one of the symptoms of the condition. T/I C A
5. What is diarrhea? Name a common cause and describe how it is treated. K/U
6. (a) What is the greatest risk associated with vomiting and diarrhea?
   (b) Use the Internet and other sources to find out the symptoms and risks associated with dehydration. K/U T/I A
7. Use the Internet and other sources to research *E. coli* infection. Based on your research, prepare a list of precautions that can be taken to help prevent *E. coli* infection. T/I
8. Licensed food establishments are required to meet certain standards of hygiene in order to maintain their licence. Use the Internet and other sources to research the provincial regulations. Write a brief report summarizing the requirements for obtaining and renewing a food service licence. T/I C A

GO TO NELSON SCIENCE

9.7 Biology JOURNAL

Scientific Detective Work

SKILLS HANDBOOK A4

ABSTRACT

Many modern medical sciences are based on the achievements of a small number of pioneer scientists whose work set the stage for new discoveries and theories. John Snow was one of these pioneers. In the 1850s, England was gripped by a cholera epidemic. The medical community accepted the miasmatic theory, which held that pollution, or "bad air," caused diseases such as cholera. John Snow's research led to the conclusion that contaminated drinking water was the source of cholera. His methodical approach to scientific research produced indisputable evidence and changed the thinking of the medical community. John Snow's approach to scientific problem solving illustrates a fundamental characteristic of science: scientific theories are always tentative and can change in the face of new evidence.

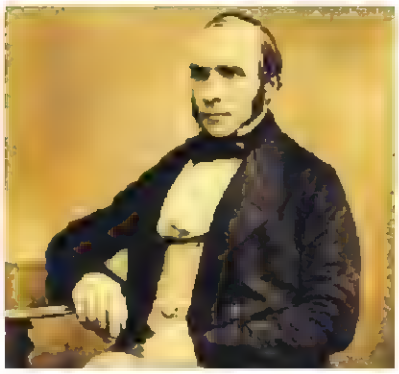


Figure 1 John Snow in 1857 at the age of 44

The first outbreak of cholera in England occurred in 1831. The main symptoms of the disease were vomiting and diarrhea. In many cases, the symptoms were so severe that people who were healthy in the morning were dead by evening. The outbreak claimed thousands of lives. A second outbreak in 1848 killed between 50 000 and 70 000, and a third outbreak in 1854 killed more than 30 000 in London alone.

John Snow: Science Sleuth

John Snow was a physician in London around the time of the second cholera epidemic (**Figure 1**). He was frustrated by unsuccessful attempts to save patients afflicted with the deadly disease. The accepted explanation of the disease at the time was called the miasmatic theory. According to the miasmatic theory, poisonous particles in the air from decomposing matter caused diseases such as cholera and the Black Death (a bacterial pandemic in the mid-1300s that killed an estimated 30 % to 60 % of Europe's population).

Snow rejected the miasmatic theory. He had observed that the first cases in an outbreak of cholera showed up in sea ports, where people had arrived from other countries that were experiencing outbreaks of the disease. It was clear to Snow that the disease was carried by people, but he was not sure how it was passed between them. Simply being in contact with a person did not necessarily mean you would contract the disease. After further investigation, Snow found evidence that the disease was spread through contact with human excrement. He suspected a connection between the cholera outbreak and a contaminated water supply.

At the time, living conditions in London were very bad. Poverty, overcrowding, and unsanitary conditions were prevalent. Sewage was often dumped into open ditches along the street, which emptied into the Thames River. The Thames stank so badly that all windows in the area had to be kept closed.

In most cases, water was supplied to local wells in London from the Thames. Based on his hypothesis that the water supply was connected to the cause of cholera, Snow mapped out the locations of all the cholera deaths in London and surrounding towns (**Figure 2**). He found that the worst outbreaks were in areas where the water was likely to be contaminated with sewage. These statistics became the key evidence in establishing the connection between cholera and the contaminated water supply.

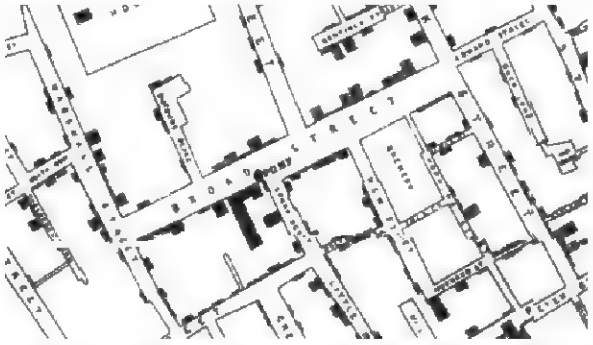


Figure 2 This diagram is a copy of Snow's original map showing where cholera-related deaths occurred in the Broad Street area. Each black bar represents a death. Data in this format provided evidence to support his hypothesis that the water supply was somehow connected. Notice the many deaths concentrated close to the Broad Street water pump.

SCIENTIFIC METHODS

Snow's conclusion is a classic example of a methodical scientific approach to finding answers and solving problems. Snow started his study in 1849, and after six years of hypothesis-based research, he had evidence that was so convincing that the authorities removed the handle of the Broad Street water pump the day after Snow presented his information. Although the epidemic was already declining at this point because most of the population had left the area, the spread of the disease in the area was halted.

Snow's evidence can be summarized as follows:

- The symptoms were intestinal and did not affect the respiratory system.
- Simply being in the same room with an infected person did not mean contracting the disease.
- Most individuals who contracted the disease were living in an area that used water from a water source contaminated with sewage.
- The infected individuals who did not live in the immediate area were confirmed to have drunk water from sources that were also likely contaminated.
- The spread of the disease halted when people stopped drinking the contaminated water.

John Snow's documentation and his collection of evidence conclusively identified the source of the cholera infections, but it did not identify the cause. An Italian scientist, Filippo Pacini, had discovered a bacterium in 1854 and had made the connection with cholera. However, his discovery was ignored by the medical community, and it is unlikely that John Snow was aware of the discovery because of limited communication at the time. It was not until 1883 that a German physician named Robert Koch conclusively established that the bacterium was indeed responsible for cholera. Snow, Koch, and others of their time are considered pioneers; their work became the basis for modern medicine and public health, and their discoveries have saved countless lives.

Cholera Today

We know today that cholera is a form of gastroenteritis, or inflammation of the lining of the gastrointestinal tract. It is caused by the bacterium *Vibrio cholerae* (**Figure 3**), which is transmitted through food or drinking water. Because it affects the lining of the small intestine, cholera is characterized by extreme diarrhea. A toxin produced by the bacteria causes the intestines to release large amounts of water, leading to severe dehydration, which can be fatal if left untreated. The incidence of cholera today is low because of public health practices such as water and sewage treatment, and is most common in developing countries. Between 2008 and 2009, there was an outbreak of cholera in Zimbabwe, with over 98 000 cases reported, including more than 4200 deaths. The main cause of this outbreak was essentially the same as the outbreaks in London in the mid-1800s—a shortage of safe drinking water in urban areas. Worldwide, the fatality rate is now extremely low because of the availability of antibiotics and simple oral or intravenous rehydration treatment.

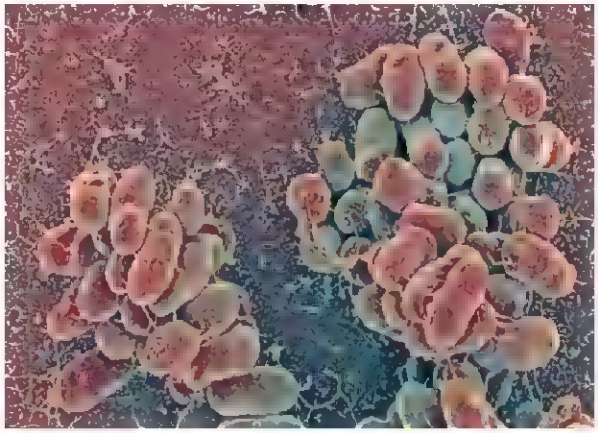


Figure 3 The bacterium *Vibrio cholerae* was unknown during the early outbreaks of cholera (SEM 22 371 X).

Further Reading

Field, D. (1985). *Science, Process and Discovery*. Toronto: Addison-Wesley Publishers Ltd. 70–82.

Morris, R.D. (2007). *The Blue Death: Disease, Disaster and the Water We Drink*. New York: Harper Collins.

GO TO NELSON SCIENCE

9.7 Questions

1. Why do you think it was so diff cult in the 1850s to identify the cause of a disease? K/U T/I
2. Describe two things that John Snow's investigation of cholera illustrates about the nature of scientific investigations. K/U T/I A
3. Explain how each piece of evidence led Snow to his conclusion that the source of the infection was the drinking water. K/U T/I A
4. Communication among scientists is an important factor in scientific discoveries. Use the Internet and other sources to investigate and compare communication methods today with those in the 1850s. Present your findings in a graphic organizer. What impact do you think communication has on scientific achievements? T/I C A
5. In your opinion, how important was Snow's work as the basis for modern medicine and public health? Explain. A
6. Why has the fatality rate dropped significantly since the early outbreaks of cholera? K/U T/I A
7. (a) Use the Internet and other sources to research the situation in London in the 1850s and the present-day situation in developing countries such as Zimbabwe. What do your findings tell you about the advances in medicine over the last century?
   (b) Given the advances in medicine and public health since the early cholera outbreaks, why do you think there are still outbreaks of cholera today? K/U A

GO TO NELSON SCIENCE

CHAPTER 9 Investigations

Investigation 9.5.1 CONTROLLED EXPERIMENT

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Factors Affecting the Digestion of Starch

Starch is a type of complex carbohydrate. Starch molecules are large polysaccharide molecules that are made up of hundreds of glucose subunits. The digestion of starch begins in the mouth with the enzyme amylase, which is found in saliva, and continues in the small intestine. During digestion, the large polysaccharide molecules are broken down by amylase into maltose, a disaccharide. Another enzyme, maltase, in the small intestine, splits each maltose molecule into two glucose molecules that can then be absorbed into the bloodstream.

In this activity you will determine if and how different factors affect the digestion of starch. Benedict's reagent is a solution that is used to test for the presence of monosaccharides and disaccharides, such as glucose and maltose.

Testable Question

SKILLS HANDBOOK A2.2

How is the digestion of starch by the enzyme amylase affected by temperature and pH?

Hypothesis/Prediction

Part A: Make a prediction about how temperature will affect the digestion of starch. Create a hypothesis to explain your prediction.

Part B: Make a prediction about how pH will affect the digestion of starch.

Variables

Identify the independent (or manipulated) and dependent (or responding) variables in this experiment. In your notebook, describe how you will measure these variables. What variables must be controlled?

Equipment and Materials

SKILLS HANDBOOK A1.2

- apron
- chemical safety goggles
- masking tape
- pen or permanent marker
- 8 test tubes
- test tube rack
- test tube tongs
- ice-water bath (0 °C)
- room-temperature-water bath
- warm-water bath (37 °C)
- hot-water bath (90 °C)
- boiling water bath
- 2 hot plates
- pipettes
- 2 thermometers
- 1 % starch suspension
- 5 % amylase solution
- 5 beakers (250 mL)
- pH 3 and pH 6 hydrochloric acid solutions
- pH 8 and pH 11 sodium hydroxide solutions
- Benedict's reagent

If hydrochloric acid or sodium hydroxide is spilled, notify your teacher immediately. Avoid any contact with skin or clothing. If these chemicals are spilled on the skin and clothing, remove the clothing immediately and rinse the skin thoroughly with running water.

Experimental Design

SKILLS HANDBOOK A2.2

Amylase is added to starch solutions under varying conditions of temperature and pH. After an appropriate time, the solutions will be tested for the presence of sugar. The presence of sugar is determined by adding Benedict's reagent to the various solutions and heating until a green, yellow, orange, or red colour appears, depending on the concentration of sugar present (**Figure 1**). No colour change after several minutes means that no sugar is present.

Relative amount of sugar	0 none	+ trace	++ little sugar	+++ some sugar	++++ much sugar
Colour	blue	blue-green	green	yellow	orange-red

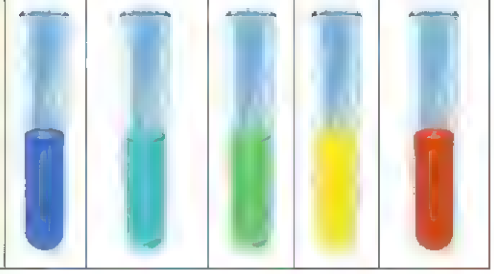


Figure 1

Procedure

SKILLS HANDBOOK A1.2, A2.2

1. Put on your apron and chemical safety goggles and follow all lab safety procedures.
2. Create an appropriate table in which to record your observations.
3. Label the test tubes 1 to 8 and place them in the test tube rack. Add 3 mL of 1 % starch suspension to each of the test tubes.

Part A: Effect of Temperature

4. Place test tube 1 in the ice-water bath. Place test tube 2 in the room-temperature-water bath. Place test tube 3 in the warm-water bath. Place test tube 4 in the hot-water bath. Let the test tubes sit in the baths for 3 min to ensure that the solution in the test tube has reached the temperature of the baths.
5. Add 5 drops of amylase solution to each of the four test tubes. Gently swirl the test tubes to mix the solutions.
6. After 10 min, conduct the Benedict's test. Add 3 mL of Benedict's reagent and swirl the tubes gently to mix the contents. Use the tongs to move the test tubes to the hot-water bath.
7. After 5 min, use the tongs to remove the test tubes from the hot-water bath. Observe the test tubes. Record your observations.

Part B: Effect of pH

8. Place test tubes 5 to 8 in the warm-water bath.
9. Add 3 mL of pH 3 hydrochloric acid to test tube 5.
   Add 3 mL of pH 6 hydrochloric acid to test tube 6.
   Add 3 mL of pH 8 sodium hydroxide to test tube 7.
   Add 3 mL of pH 11 sodium hydroxide to test tube 8.
   Gently swirl the test tubes to mix the solutions.
10. Add 5 drops of amylase solution to each of the four test tubes. Mix the solutions by gently swirling the test tubes.
11. After 10 min, add 3 mL of Benedict's reagent and gently swirl the tubes to mix the solutions. Then use tongs to move the test tubes to the boiling-water bath.
12. After 5 min, use the tongs to remove the test tubes from the boiling-water bath. Observe the test tubes. Record your observations.
13. Dispose of the test tube contents as directed by your teacher. Rinse the test tubes and clean up your work space.

Analyze and Evaluate

(a) What variables were measured, recorded, and/or manipulated in this investigation? What type of relationship was being tested? T/I

(b) How did temperature affect the digestion of starch? How did pH affect the digestion of starch? T/I

(c) Why do you think test tubes 5 to 8 were placed in the warm-water bath in Step 8? T/I

(d) Based on the factors investigated here, what were the best conditions for the digestion of starch? Use your results to explain your conclusion. T/I

(e) Were your predictions accurate? Explain. T/I

(f) Do your observations support your hypothesis about the effect of temperature on the digestion of starch? Explain. T/I

(g) Evaluate the quality of the evidence you used to draw your conclusion. How could you modify the procedure to improve the quality of the evidence? T/I A

Apply and Extend

(h) Based on your results, what is likely to happen to the digestion of starch when food reaches the stomach? T/I

(i) Based on your knowledge of the digestive processes, what happens to the digestion of starch when food passes into the duodenum? Explain why. K/U A

(j) Amylase, like other enzymes, is a protein. Proteins are complex molecules whose shape can be modified by high temperatures. What evidence from this investigation might confirm this characteristic of proteins? T/I

(k) Would you expect to find amylase in the saliva of cats or other carnivores? Explain your reasoning. A

(l) Suggest other physical conditions that might affect the digestion of starch. Select one and plan a similar experiment to determine its effect. Once your plan is approved by your teacher, carry out your investigation. T/I

(m) Based on your observations in this investigation, predict what the optimal conditions would be for enzymes that act in the stomach. T/I A

CHAPTER 9 SUMMARY

Summary Questions

1. Summarize your learning in the chapter by creating a three-column table. Label the columns as follows: "Things I Already Knew"; "Things I Knew but Learned More About"; and "New Things I've Learned." Use the Key Concepts listed at the beginning of the chapter, on page 394, as guidelines to ensure that you have a complete summary.
2. Return to the Starting Points questions at the beginning of the chapter on page 394. Answer these questions using what you have learned in this chapter. Compare your answers with those that you gave at the beginning of the chapter. How has your understanding changed? What new knowledge and skills do you have?

Vocabulary

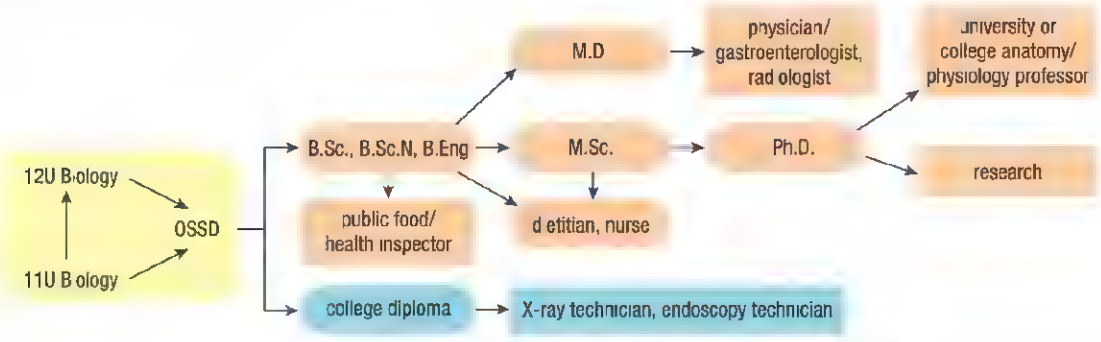
nutrient (p. 396)
metabolism (p. 397)
catabolism (p. 397)
anabolism (p. 397)
metabolic rate (p. 397)
basal metabolic rate (p. 398)
hormone (p. 401)
triglyceride (p. 402)
vitamin (p. 403)
mineral (p. 403)
gastrovascular cavity (p. 406)
gastrointestinal tract (GI tract) (p. 407)
enzyme (p. 408)
amylase (p. 408)
mucus (p. 408)
esophagus (p. 409)
peristalsis (p. 409)
sphincter (p. 409)
chyme (p. 409)
gastrin (p. 410)
pepsin (p. 410)
ulcer (p. 410)
villus (p. 413)
microvillus (p. 413)
lacteal (p. 413)
secretin (p. 415)
trypsin (p. 415)
enterokinase (p. 415)
lipase (p. 416)
bile (p. 416)
passive transport (p. 416)
concentration gradient (p. 416)
facilitated diffusion (p. 417)
active transport (p. 417)
cecum (p. 418)
colon (p. 418)
rectum (p. 418)
anus (p. 418)
egestion (p. 419)
feces (p. 419)
endoscopy (p. 419)
nausea (p. 421)
emesis (p. 421)
diarrhea (p. 422)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or postgraduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select two careers related to the digestive system of animals that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



GO TO NELSON SCIENCE

CHAPTER 9 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which of the following is the SI unit used to measure the energy stored in food? (9.1) K/U
   (a) kilogram
   (b) watt
   (c) kilojoule
   (d) lipid
2. The rate at which the body converts stored energy into working energy is called the
   (a) metabolic rate
   (b) anabolic rate
   (c) digestive rate
   (d) chemical rate (9.1) K/U
3. Which of the following is one of three main types of carbohydrates? (9.2) K/U
   (a) amino acids
   (b) triglycerides
   (c) polysaccharides
   (d) hormones
4. Which of the following would be the best way to provide your body with enough vitamin D over a one week period? (9.2) K/U
   (a) drink eight glasses of water daily
   (b) sit in the sun for 10 min every other day
   (c) eat four servings of meat
   (d) lower your overall intake of Calories
5. An excessive consumption of lipids may lead to
   (a) vitamin A deficiency
   (b) dehydration
   (c) anemia
   (d) obesity (9.2) K/U
6. What is one of the functions of the sphincter muscles in the digestive tract? (9.4) K/U
   (a) to move food into and out of the stomach
   (b) to trigger the lungs to cough
   (c) to open and close the jaw
   (d) to contract and expand the liver
7. Digestion is complete and most of the nutrients have been absorbed once the digested material reaches the
   (a) stomach
   (b) pancreas
   (c) small intestine
   (d) large intestine (9.5) K/U
8. If you are vomiting and have diarrhea, what is likely to be your doctor's main concern? (9.6) K/U
   (a) that you do not develop a high fever
   (b) that you do not become dehydrated
   (c) that you do not develop jaundice
   (d) that you do not lose too much weight
9. What did John Snow's documentation and evidence prove? (9.7) K/U
   (a) Water contaminated by raw sewage was the source of cholera infections.
   (b) Cholera was not the dangerous disease people thought it was.
   (c) Poisonous particles in the air from decomposing matter were spreading cholera.
   (d) By avoiding those infected with cholera, healthy individuals would not be at risk.

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

10. The rate at which energy is used by an organism when it is at rest is referred to as the basal metabolic rate. (9.1) K/U
11. Whether you are male or female has no impact on your metabolic rate. (9.1) K/U
12. Most plant proteins contain all eight essential amino acids. (9.2) K/U
13. Like the digestive systems of many other animals, the human digestive system is a complete digestive system. (9.3) K/U
14. The stomach has three layers, each of which has a special structure and function. (9.4) K/U
15. Stomach acid is strong enough to kill most bacteria that enter the stomach. (9.4) K/U
16. Most digestion and absorption of nutrients takes place in the small intestine. (9.5) K/U
17. The liver is the smallest internal organ of the body. (9.5) K/U
18. Nausea and vomiting are diseases that affect the digestive system. (9.6) K/U
19. There remain outbreaks of cholera in the world today. (9.7) K/U

To do an online self-quiz,
GO TO NELSON SCIENCE

CHAPTER 9 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. Which of the following is taken into account in estimating a person's BMR? (9.1) K/U
   (a) age
   (b) height
   (c) sex
   (d) all of the above
2. Proteins are made up of long chains of smaller molecules called
   (a) glucose
   (b) amino acids
   (c) fatty acids
   (d) polysaccharides (9.2) K/U
3. Vitamins A, D, E, and K are fat soluble. What does this mean? (9.2) K/U
   (a) They dissolve in fat.
   (b) They dissolve in water.
   (c) They dissolve in both fat and water.
   (d) They cannot dissolve.
4. Which of the following shows the correct order of the main steps in human digestion? (9.3) K/U
   (a) absorption, ingestion, egestion, digestion
   (b) egestion, ingestion, absorption, digestion
   (c) ingestion, digestion, absorption, egestion
   (d) digestion, ingestion, absorption, egestion
5. What prevents food from entering the lungs from the esophagus? (9.4) K/U
   (a) the raising of the larynx against the epiglottis
   (b) the raising of the soft palate in the pharynx
   (c) the wave-like contractions called peristalsis
   (d) the circular movements of the sphincters
6. Which of the following best describes pepsin's role in the stomach? (9.4) K/U
   (a) a hydrochloric acid–releasing hormone
   (b) a protein-digesting enzyme
   (c) a bacteria-killing acid
   (d) none of the above
7. In which section of the small intestine are most nutrients absorbed? (9.5) K/U
   (a) the duodenum
   (b) the jejunum
   (c) the ileum
   (d) the cecum
8. Which of the following is most likely to occur if not enough water is absorbed in the large intestine? (9.5) K/U
   (a) diarrhea
   (b) dehydration
   (c) vomiting
   (d) constipation

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

9 Your energy requirement is the same each day, regardless of your physical activity. (9.1) K/U

10. Your body needs six essential nutrients in order to stay healthy. (9.2) K/U
11. Your digestive tract is actually much longer than your body. (9.3) K/U
12. Gastric juice is not a particularly strong acid. (9.4) K/U
13. Most of the digestion of carbohydrates, proteins, and fats takes place in the stomach. (9.5) K/U
14. Diarrhea is a common symptom of food-borne illnesses. (9.6) K/U

15 We know today that cholera is an airborne disease spread by coughing or sneezing. (9.7) K/U

Write a short answer to each question.

16. List three factors that might affect one's metabolic rate. (9.1) K/U
17. Define basal metabolic rate. (9.1) K/U
18. What are the essential nutrients your body needs to stay healthy? (9.2) K/U

19 List the three main types of carbohydrates. (9.2) K/U

20. What balance is required to maintain your body mass? (9.2) K/U
21. Which organ system transports absorbed nutrients to the cells of the body? (9.3) K/U

22. **Figure 1** shows a diagram of the stomach. In your notebook, match the following labels to the appropriate letter in Figure 1: esophagus, duodenum, mucosa, submucosa, serosa, muscularis, pyloric sphincter, gastroesophageal sphincter. (9.4) K/U

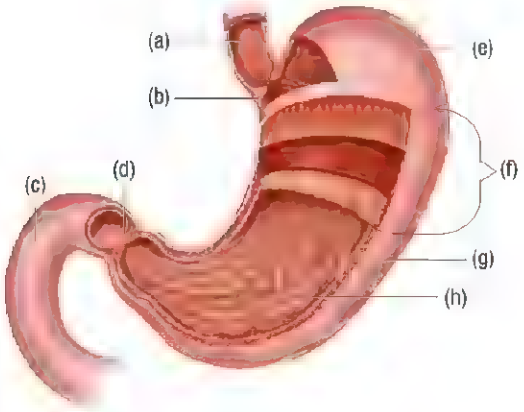


Figure 1 The human stomach

23. Where is chyme produced? (9.4) K/U
24. What did the medical community believe caused ulcers, before the 1980s? (9.4) K/U
25. List the three sections of the small intestine. (9.5) K/U
26. What main step in the digestive process occurs after the physical and chemical breakdown of proteins, carbohydrates, and lipids? (9.5) K/U
27. Where is most of the water in the food we eat and in the liquids we drink absorbed? (9.5) K/U
28. In the 1800s cholera outbreaks in London, what was determined to be the source? (9.7) K/U

Understanding

29. Some living things require much more food than others. There are many factors that determine how often an animal needs to eat. (9.1) K/U
    (a) Why does a gerbil need to eat much more often than a frog?
    (b) Why does the average teenage girl need to eat more than the average 65-year-old woman?
30. Judy is a 46-year-old woman who is 160 cm tall with a mass of 60 kg. Using the formula below, calculate Judy's basal metabolic rate. (9.1) T/I

$$BMR = [655 + (9.6 \times \text{mass in kg}) + (1.8 \times \text{height in cm}) - (4.7 \times \text{age in years})] \times 4.18$$

31. Suppose you are a vegetarian. Explain briefly how you could compensate for the needed protein in your diet that you would be missing by not eating meat. (9.2) K/U T/I
32. Fats and oils (two familiar types of lipids) usually raise a warning flag when we think about healthy eating, but they are essential components of any diet. (9.2) K/U
    (a) What benefits do lipids provide to our bodies?
    (b) Explain the difference between unsaturated and saturated fats.
33. Explain the differences and similarities between anorexia nervosa and bulimia. (9.2) K/U
34. As you learned in Section 9.3, each animal species has unique adaptations that enable it to obtain and digest food. Explain the main difference between the digestive system of a flatworm and that of a human. (9.3) K/U
35. Suppose you have discovered the skull of an animal with the teeth intact. What clues would you look for to help you determine whether the skull belonged to a herbivore, carnivore, or omnivore? (9.4) K/U T/I
36. Explain why someone who works in a bakery might produce more saliva throughout the course of a day than someone who works in a bank. (9.4) K/U T/I
37. Describe the motions that seal the nasal passages, mouth, and trachea during the swallowing reflex. Draw a diagram to support your description. (9.4) K/U T/I C
38. Explain the function of each of the four layers of the stomach. (9.4) K/U T/I
39. What is likely to be going wrong between your stomach and your esophagus if you are feeling the symptoms of acid reflux? (9.4) K/U T/I
40. Explain why the inner surface area of the small intestine is actually larger than it would appear from the outside by a factor of up to 500. (9.5) K/U
41. There are several different mechanisms for absorption in the small intestine. These mechanisms can be categorized as either passive transport or active transport. (9.5) K/U
    (a) Explain the difference between passive transport and active transport.
    (b) Under which of these two mechanisms for absorption would osmosis be categorized?
42. Explain why the names given to the large intestine and small intestine could be misleading. (9.5) K/U T/I
43. Which of the major digestive organs is most affected by alcohol consumption? Why? (9.5) K/U T/I

44. Our bodies cannot digest cellulose and most other fibres, yet fibre is a very important part of our diet. Explain what roles fibre plays in the digestive system and why we need it in our diet. (9.5) K/U T/I

45. Historically, the only way to directly examine the digestive system was to perform surgery. Today, medical scientists and technologists have developed considerably less invasive methods, such as endoscopy. (9.5) K/U
    (a) Define endoscopy.
    (b) Describe how an endoscope works and what it can be used for.

46. If you were going to have your gall bladder removed, what would some of the benefits be in having an endoscopic procedure rather than more invasive surgery? (9.5) K/U T/I

47. Explain what happens in a person's digestive tract to bring about an episode of diarrhea. (9.6) K/U

48. Each year in Canada, there are an estimated 11 million to 13 million cases of food-borne illness, and many of these result from improper storage and cooking of meat, poultry, and seafood. (9.6) K/U
    (a) Why is consuming undercooked ground beef potentially dangerous?
    (b) What symptoms might arise following the consumption of undercooked ground beef?

49. In many ways, living conditions in 1800s London were perfect for cholera epidemics. Describe these conditions and why they led to such devastating outbreaks of this disease. (9.7) K/U

Analysis and Application

50. Different lifestyles and careers can result in completely different energy requirements. Even between two similarly sized people of the same sex, the variance can be substantial. (9.1) T/I A
    (a) Compare the energy requirements of an office worker and a landscaper who mows lawns with a push mower for 8 hours each day.
    (b) What might happen over the course of one year if they each consume the same number of Calories daily?

51. Why are fats and oils categorized as good or bad? Give examples of good fats and bad fats. (9.2) K/U T/I

52. As you learned in Section 9.1, everyone's metabolic rate is different. This is because the metabolic rate depends on a number of factors. Use what you have learned about metabolic rate to answer the questions below. (9.1) K/U T/I A
    (a) Copy **Table 1** into your notebook. Complete the table by listing the higher metabolic rate (male/female, larger/smaller, older/younger, and more active/less active) in the first row and the lower rate in the second row.

Table 1 Metabolic Rates

	Sex	Body size	Age	Activity level
higher				
lower				

    (b) Determine whose metabolic rate might be higher: yours, or that of a large, inactive 45 year old woman. Explain your answer.

53. Individuals suffering from bulimia usually do their best to hide their condition from those around them. Considering what you have learned about this eating disorder, how might you be able to recognize whether a friend of yours is suffering from this disease? (9.2) K/U T/I A

54. An old English proverb says, "Don't dig your grave with your knife and fork." In what situation(s) might this proverb be used? Explain what the proverb means. (9.2) T/I A

55. Often, simply the sight or smell of food triggers the salivary glands to secrete watery fluid called saliva. Explain why such a reaction might involuntarily take place and what purposes it might serve. (9.4) T/I

56. Propose a reason why the stomach has three layers of muscle while the rest of the gastrointestinal track has only two layers. (9.4) K/U T/I A

57. Drs. Robin Warren and Barry Marshall changed the way the medical and scientific community looked at ulcers. Based on Warren and Marshall's research, ulcers are now diagnosed and treated differently. (9.4) K/U T/I A
    (a) Describe what was different about Marshall's approach in trying to support his hypothesis.
    (b) What benefits and disadvantages did his unorthodox approach have?

58. Explain why the lining of your stomach needs to be replaced about every three days. Hypothesize what it might be like for us and for our stomachs if this were not the case. (9.4) K/U T/I

59. (a) Describe the digestion of a meal of chicken, broccoli, and rice as it moves through the digestive system, from the mouth to the large intestine. Be sure to describe the enzymes and hormones used.
    (b) How would the digestion of the meal in (a) differ depending on whether or not the meal included butter or oil? (9.3, 9.4, 9.5) K/U A

60. The human digestive tract is a very complex system. Each organ along the way plays an integral role in the body's digestion and processing of essential nutrients. Explain why you think our digestive systems are so complex. Do they need to be as complex as they are? Why or why not? (9.4, 9.5) K/U T/I

61. (a) Compare and contrast the roles of the gall bladder and liver.
    (b) Predict how each of these roles would be affected following gall bladder removal surgery. (9.5) K/U T/I A

62. (a) Does **Figure 2** represent simple diffusion, facilitated diffusion, or active transport?

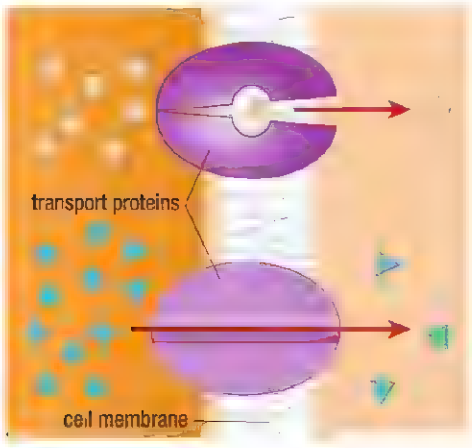


Figure 2

    (b) Draw diagrams to represent the other mechanisms for absorption that Figure 2 does not show.
    (c) Explain how the diagrams show the differences between simple diffusion, facilitated diffusion, and active transport. What information about these mechanisms do the diagrams not show? (9.5) K/U T/I C

63. Imagine you are a surgeon working before endoscopy was introduced. Write a brief statement about why a new, less invasive technology is needed in surgical procedures. (9.5) T/I C A

64. Why is it important to recognize that vomiting and diarrhea are symptoms of some underlying condition rather than diseases or disorders? (9.6) K/U T/I

65. Compare and contrast two types of bacterial infections that can cause diarrhea. Make distinctions between their sources, the symptoms they cause, and preventive measures one can take to avoid being infected. (9.6) K/U T/I A

Evaluation

66. As you have learned in Section 9.1, your physical activity is the only factor that affects metabolic rate that you can control. (9.1) K/U A
    (a) Devise three different exercise programs through which you could alter your metabolic rate.
    (b) Pick the program that you think is best for you, and describe how it would best be implemented.

67. Would basal metabolic rate (BMR) be a good measurement of energy needs for a body builder? Would it be a good measurement for a sumo wrestler? Explain your thinking. (9.1) K/U T/I A

68. A popular weight loss diet recommends eliminating carbohydrates from the diet and increasing the amounts of protein and fat. This diet has proven successful for many individuals. (9.1) K/U T/I A
    (a) Based on what you have learned in this chapter, do you think this is a good approach to weight loss? Explain your answer.
    (b) Recommend and justify an alternative healthier approach to weight loss.

69. A nutritionist analyzed the diet of a hospital patient and included the following statistics in her report. (9.2) K/U T/I A
    - 40 % of energy intake from fat
    - 40 % of energy intake from carbohydrates
    - 20 % of energy intake from proteins
    - energy intake ÷ energy output = 1.25
    - deficient in vitamins A and D
    - deficient in calcium
    - water intake: approximately 1 L/day

    (a) What types of health problems might this patient experience?
    (b) If you were the nutritionist, what recommendations would you make to correct any problems related to diet?

70. The Mediterranean-style diet emphasizes fruits, vegetables, fish, and whole grains. Olive oil is the main source of fat in the Mediterranean diet. Olive oil contains monounsaturated fat, a type of fat that reduces LDL cholesterol levels. Research shows that the incidence of heart disease in countries where people follow a Mediterranean-style diet is much lower than in countries where the diet includes higher proportions of animal protein and fats. What conclusions can you draw from these observations? Do you think that heart disease can be eliminated by following a Mediterranean-style diet? Explain your answer. (9.2) T/I A

71. Create a daily diet for yourself that you think meets the recommendations of Health Canada's food guide. Be sure that your diet includes all six essential nutrients you need to stay healthy. Try to include a variety of foods and food groups. (9.2) K/U T/I A

72. Choose two structures along the human digestive tract. Predict what might happen in each case if that structure completely broke down and no longer performed its task. (9.5) K/U T/I A

73. A patient visits her doctor complaining of digestive system problems, specifically nausea and vomiting. The doctor asks the following questions in an attempt to determine the exact nature and possible cause of the problems.

- When did the vomiting begin? How long has it lasted?
- Does it occur several hours after meals?
- Have you ever had symptoms like this before?
- Do you think it could be something you ate? Did other people who ate the same things have the same symptoms?
- Have you ever vomited blood? Did it look like fresh blood or was it black, like coffee grounds?
- Do you have a history of ulcers?
- Is the nausea or vomiting severe enough to cause unintentional weight loss?
- Is the vomiting self-induced?
- Have you been travelling? Where?
- What medications do you take? (9.2, 9.4, 9.5, 9.6) K/U T/I A

(a) Pick any five of these questions and explain why you think the doctor asked each question.
(b) What possible disorder(s) do you think the doctor suspects?
(c) What diagnostic tests do you think the doctor might recommend to help her make an accurate diagnosis?

74. An investigation was carried out to determine the effect of fibre in the diet on the formation of cancerous tumours in the large intestines of rats. All 100 of the rats in the investigation received a chemical that is known to cause tumours to form in the large intestine. The rats were then divided into two groups of 50 rats each. The control group was fed a normal diet. The experimental group was fed a diet with added fibre. Each week the rats were checked to see if any tumours had formed in the large intestine. Study the results in the graph in **Figure 3** and answer the questions that follow. (9.2, 9.5) T/I A

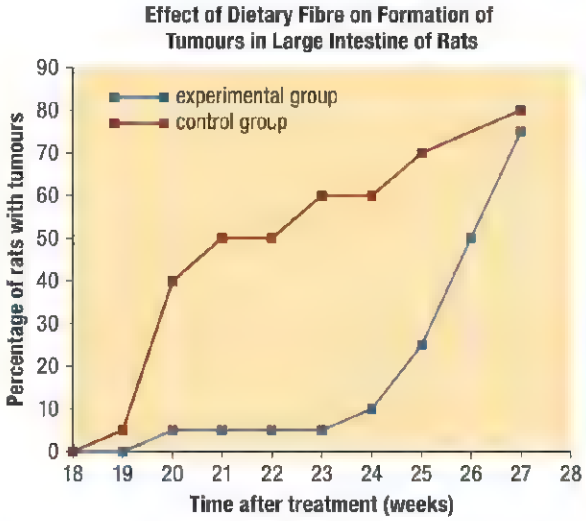


Figure 3

(a) What are the dependent variable and the independent variable in this investigation?
(b) Describe how the investigation was controlled. In your description identify other possible variables that should have been controlled.
(c) At what point in the investigation was a difference in the two groups observed?
(d) At what point in the investigation were tumours observed in 50 % of the rats in
(i) the control group
(ii) the experimental group
(e) Using the results of this investigation, evaluate the effectiveness of fibre in preventing large intestine cancer in rats.

75. You are the head of Health Canada, the department of the Government of Canada responsible for national public health. In your role, compose a letter on the dangers of consuming undercooked meats. Include in your letter the warnings and symptoms to look out for if food-borne illness should occur as a result of consuming undercooked meats. Finally, advise public eateries on the risks involved and proper safety measures to take. (9.6) K/U T/I C

76. Vomiting is viewed by almost everyone as a very unpleasant experience. Defend vomiting as a positive mechanism. Argue in favour of this bodily function by citing all that is positive about it. (9.6) T/I A

77. Suppose you are the mayor of London in 1850. As leader of this city, devise a plan to deal with the outbreak of cholera and rid your constituents of this disease once and for all. Your plan should include details of how the sick will be tended to, how you will rid your city of this epidemic, and what preventive measures you will take to ensure repeat outbreaks do not occur. Communicate your plan to the people of London in the form of a written statement. (9.7) K/U T/I C A

Reflect on Your Learning

78. In Section 9.1, you learned about food for growth, food for energy, and factors that affect energy requirements. Based on what you read, how will you apply what you learned to your own life and behaviours? Describe how the information you obtained might change your own eating habits (energy intake) and your daily exercise regimen (energy output). T/I A

79. Now that you know just how complex your digestive system is, devise a way through which you might teach others about this very complicated system. In an original lesson, devise a method you can use to help fellow students learn and remember the essential functions of the various organs along the human digestive tract. T/I C A

80. Most medical breakthroughs are not sudden discoveries but are made only after years of research. Based on examples you have learned about in this chapter and other examples you might be aware of, what characteristics of scientific inquiry are important in medical research? Why do you think the scientific process is essential in medical research? T/I A

Research

GO TO NELSON SCIENCE

81. Use the Internet and other sources to research anorexia nervosa and bulimia. Write a pamphlet aimed at informing the student population of your school about these disorders. Include information about the types of people that are more likely to suffer from anorexia nervosa and bulimia, the behaviour of these individuals, the health risks associated with the disorders, as well as available treatments. Be sure to provide information on resources available to people in your community who are suffering from the disorder or suspect a family member or friend is suffering from the disorder. T/I C A

82. Body Mass Index (BMI) is a ratio of a person's height and weight. It is used to estimate whether a person has a healthy body weight based on their height. Use the Internet and other sources to research Body Mass Index. K/U T/I A
    (a) How is BMI determined?
    (b) BMI is usually expressed as a simple number. What unit should be attached to this value?
    (c) What is the purpose of this ratio and how is the information used?
    (d) BMI is an estimate. What are the shortcomings of BMI as an indicator of appropriate or inappropriate body weight?
    (e) Although it has shortcomings, why is BMI so widely used?
    (f) Use the formula or a chart to determine your own BMI. In which category does your value fall?
    (g) In the general population the average BMI for a 16-year-old female should be between 16.8 and 24.6. Jill, a healthy, athletic individual with no significant health problems, has calculated her BMI to be 26. Do you think Jill is overweight? Propose an explanation for the discrepancy between her actual BMI and the population average.

83. Use the Internet and other sources to research the history of vegetarianism. Trace vegetarianism's following, and write a news-story-styled report to present to your class. In your story, give details of what it means to be a vegetarian, all of the types of vegetarianism, and how someone can choose this diet for his or her life while retaining a high level of digestive health and fitness. T/I C A

84. Jaundice is a condition marked by yellowish staining of the skin and the whites of the eyes (**Figure 4**). Use the Internet and other sources to research the symptoms and possible causes of jaundice. Write a brief report of your findings. T/I C A

Figure 4 The eye of an individual suffering from jaundice

85. Use the Internet and other sources to research colitis, a disorder of the digestive system. Write a brief report on the symptoms, possible causes, and treatments for the disorder. T/I C A

CHAPTER 10

The Respiratory System

KEY CONCEPTS

After completing this chapter you will be able to

- explain the overall functions of the respiratory system
- explain the structure and function of the main organs of the human respiratory system
- identify the factors that affect lung capacity and explain the relationship between exercise and lung capacity
- explain the processes by which oxygen is absorbed and carbon dioxide is eliminated from the cells and the body
- demonstrate an understanding of common diseases and conditions that interfere with gas exchange
- evaluate technologies that are used in the diagnosis and treatment of respiratory diseases or disorders
- discuss issues related to lifestyle choices and their effects on the respiratory system

How Do Organisms Exchange Gases with Their Environment?

Although the creature on the opposite page looks like a monster from a science-fiction movie, it is actually too small to be seen with the unaided eye. The actual length of the dust mite shown here is about 0.3 mm. Dust mites are relatives of spiders and ticks. They feed on dead skin cells that fall off our bodies. They are found everywhere in our homes, but bedding and mattresses are favoured environments with ideal conditions: warm and humid with a plentiful supply of food. They can also be numerous—as many as two million in the average double bed—depending on the conditions of the environment.

People are mostly unaware of the presence of dust mites, but they create a significant health problem for some people. Their droppings contain traces of enzymes that help them digest human skin cells, which are their primary food source. When dust containing these enzymes gets into the air, people inhale it. In some people, the enzymes cause an allergic reaction. The most common symptom of a dust mite allergy is a swelling of a person's airways, causing difficulty in breathing. Breathing difficulty can lead to a reduction in the supply of oxygen to the body, which has potentially serious implications for the health of the individual.

Most cells cannot perform their functions without a continuous supply of oxygen, so all plants and animals need oxygen to survive. In humans, a dust mite allergy is just one example of many factors that can interfere with the process of obtaining oxygen. Often we only become aware of these factors when a respiratory problem occurs and we look for an explanation and a solution to the problem.

In this chapter you will explore why cells need oxygen. You will develop an understanding of the structures that are used to exchange gases with the environment and of the processes by which gases are exchanged. You will also explore some of the diseases and conditions that interfere with gas exchange, as well as the technologies used to treat them.

STARTING POINTS

Answer the following questions using your current knowledge. You will have an opportunity to revisit these questions later, applying concepts and skills from the chapter.

1. Why are dust mites only a problem for some individuals?
2. Why do you think all the cells of the body need oxygen?
3. What is the difference between breathing and cellular respiration?
4. Give examples of factors that can prevent the human respiratory system from providing an adequate supply of oxygen to the cells of the body.
5. Describe a respiratory disease that you are aware of. In your description, include the symptoms and the treatments of the disease and how the disease affects an individual's life.

Mini Investigation

Modelling Breathing in a Single Lung

Skills: Performing, Observing, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A1.2, A2.1

Models are useful tools for understanding the principles behind real-world phenomena. While the structure of the model may not resemble the real thing, models can accurately illustrate the function of the structure.

Equipment and Materials: 2 L clear pop bottle with bottom cut off; balloon; glass or vinyl tubing; one-hole rubber stopper; tied balloon with the top cut off; rubber band (or masking tape)

1. Use the materials listed above to construct a model of the respiratory system similar to the one shown in **Figure 1**.

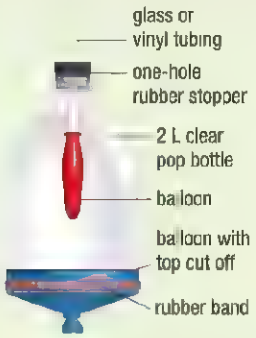


Figure 1 A model of breathing in a single lung

2. Pull down on the balloon at the bottom of the bottle (this represents the diaphragm). Observe what happens to the balloon inside the bottle.
3. Push up on the diaphragm. Observe what happens to the balloon inside the bottle.

A. Using what you know about the respiratory system, explain how your model represents breathing in a single lung. KU TI A

B. Describe what happened when you pulled down on the diaphragm. Explain this using what you already know about air pressure. TI A

C. Explain what happened when you released the diaphragm. TI A

D. Describe what happened when you pushed up on the diaphragm. TI

E. Do you think this model is a good representation of the respiratory system? Explain your reasoning. TI A

10.1 The Need for a Respiratory System

Without being aware of it, you take between 17 000 and 29 000 breaths every day, depending on your age and level of physical activity. That means you take about 500 million to 750 million breaths over the course of your life! You can stop breathing briefly, but it automatically resumes, regardless of how hard you try. Breathing is so important to us that it cannot be left to conscious control.

The air we breathe is a mixture of different gases: 78 % nitrogen, 21 % oxygen, 1 % argon, 0.04 % carbon dioxide, and lesser amounts of other gases. It is the oxygen in the air that we need. Without it, we can survive for only a few minutes.

Aerobic Cellular Respiration: The Need for Oxygen

aerobic cellular respiration the series of chemical reactions that occur in the cel that provide energy and consume oxygen

All animal and plant cells need oxygen to survive. These cells use oxygen to obtain energy from food. The process in which oxygen is used to obtain energy from food is called **aerobic cellular respiration**. Energy is released in a cell when glucose (a sugar molecule) reacts with oxygen to form carbon dioxide and water. The basic equation for aerobic cellular respiration is as follows:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

(glucose + oxygen → carbon dioxide + water + energy)

phosphorylation the addition of a phosphate group to a molecule; in aerobic cellular respiration the phosphate group is added to ADP, creating the ATP molecule in which energy is stored

About 64 % of the energy released during cellular respiration is released as thermal energy. This thermal energy helps birds and mammals maintain a constant body temperature. The rest of the energy, about 36 %, is stored in molecules called adenosine triphosphate (ATP). ATP is formed when energy from the breakdown of glucose is used to attach a phosphate group (P_i) onto a molecule called adenosine diphosphate (ADP). The process that forms ATP from ADP, phosphate, and energy is called **phosphorylation** (**Figure 1**). For each molecule of glucose that undergoes cellular respiration, 36 molecules of ATP are formed.

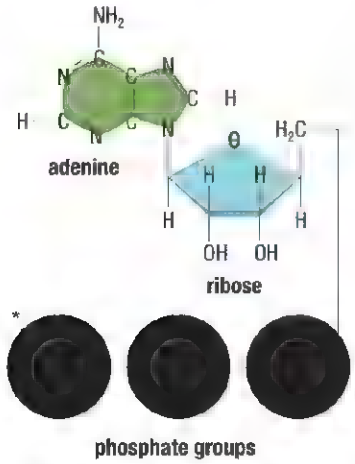


Figure 1 The ATP molecule is formed by adding a third phosphate group to an ADP molecule.

Cells use ATP to power almost all of their energy-requiring processes, such as growth, movement, and building new molecules. Energy for these cellular processes is obtained when ATP reacts with other molecules, reforming ADP and the phosphate group. The released energy is then able to do work. The ADP and phosphate are continuously recycled and recharged with energy to form ATP molecules.

The following expanded formula for cellular respiration shows the storage of energy by the conversion of ADP to ATP and the release of some of the energy as thermal energy:

$$C_6H_{12}O_6 + 6O_2 + 36\,ADP + 36\,P_i \rightarrow 6CO_2 + 6H_2O + 36\,ATP + \text{thermal energy}$$

(glucose + oxygen + adenosine diphosphate + phosphate → carbon dioxide + water + adenosine triphosphate + thermal energy)

The carbon dioxide and most of the water produced during cellular respiration are released to the environment as waste products.

Gas Exchange and Ventilation

gas exchange the processes whereby the body cells obtain oxygen and get rid of carbon dioxide

You have learned how oxygen is required to obtain energy from food in the process of aerobic cellular respiration. How is oxygen supplied to the body cells to make aerobic cellular respiration possible? **Gas exchange** is the process by which oxygen diffuses into the body cells and carbon dioxide diffuses out of the cells.

In simple organisms such as sponges and jellyfish, gas exchange is a simple process. Oxygen diffuses directly from the surrounding environment through the cell membrane into the cells. Carbon dioxide diffuses directly from the cells of these organisms through the cell membrane into the environment.

The process is different for humans, fish, and most other large multicellular animals because they contain many cells in their bodies that do not come in contact with the external environment (the air or water). These organisms have special organ systems that supply oxygen to all cells of the body and remove carbon dioxide.

In humans and other mammals, gas exchange occurs at two locations: the lungs (**Figure 2(b)**) and the body cells (**Figure 2(c)**). In the lungs, oxygen diffuses from the air into the bloodstream. Oxygen is transported through the bloodstream and diffuses into all the cells of the body. The cells of all tissues in the body are surrounded by a fluid called tissue fluid (also known as interstitial fluid). Oxygen diffuses from the blood into the tissue fluid, and from there into the cells. At the same time, carbon dioxide diffuses from the cells into the tissue fluid, then into the bloodstream. Carbon dioxide is transported through the bloodstream to the lungs, where it diffuses into the air. The process of moving oxygen-rich air to the lungs and carbon dioxide–rich air away from the lungs is called **ventilation**, or breathing (**Figure 2(a)**).

ventilation the process in more complex organisms that ensures a flow of oxygen-rich air to the lungs

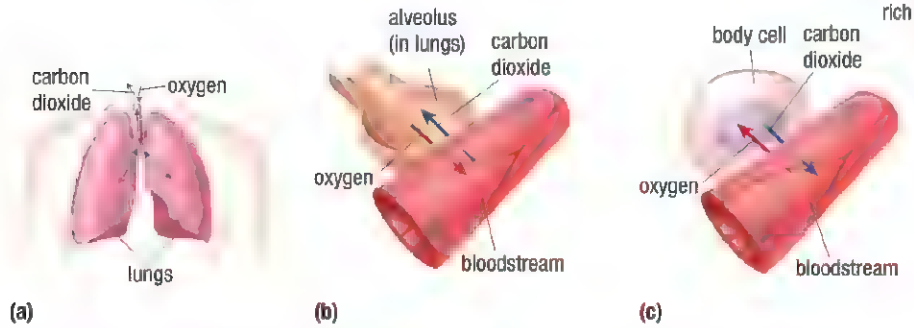


Figure 2 (a) Ventilation brings a supply of air containing oxygen to the lungs. (b) Gas exchange occurs in the lungs, where oxygen diffuses from the air into the bloodstream and carbon dioxide diffuses from the bloodstream into the air. (c) Gas exchange also occurs in the body cells. Oxygen diffuses from the bloodstream into each body cell. Carbon dioxide diffuses from the cells into the bloodstream to be carried back to the lungs for removal.

10.1 Summary

- All plants and animals require oxygen for aerobic cellular respiration.
- Aerobic cellular respiration is a series of chemical reactions that use oxygen to obtain energy from food molecules. The waste products of aerobic cellular respiration are water and carbon dioxide.
- Ventilation brings a continuous supply of air to the lungs.
- Gas exchange by diffusion occurs at two locations: the lungs and the body cells. In the lungs, oxygen diffuses into the bloodstream and carbon dioxide diffuses out of the bloodstream. At each body cell, oxygen diffuses from the bloodstream into the cell and carbon dioxide diffuses from the cell into the bloodstream.

10.1 Questions

1. What happens to the energy that is produced during aerobic cellular respiration? K/U
2. Explain the importance of the ATP molecule. K/U A
3. Phosphorylation is like charging a rechargeable battery. Explain this analogy. K/U T/I A
4. Explain the differences between ventilation and gas exchange. How are these processes related to aerobic cellular respiration? K/U T/I A
5. Use a two-column table to compare gas exchange in a jellyfish with gas exchange in a dog. K/U T/I C

10.2 Respiratory Structures and Processes

Take a deep breath! You have just captured between 3 L and 4 L of air in your lungs. We are completely surrounded by air. Remember from your previous science studies that air is a fluid consisting of a number of gases, including oxygen and carbon dioxide. Aquatic organisms such as fish are surrounded by water. Water is also a fluid that usually has some oxygen and carbon dioxide dissolved in it.

The structures and mechanisms for obtaining oxygen vary significantly depending on the size of the organism and where it lives.

Respiratory Structures in Mammals

The human respiratory system is typical of mammalian respiratory systems. It has four important structural features that enable it to function properly:

- a thin permeable respiratory membrane through which diffusion can occur
- a large surface area for gas exchange
- a good supply of blood
- a breathing system for bringing oxygen-rich air to the respiratory membrane

The Structure of the Lungs

Investigation 11.1.1

Fetal Pig Dissection (page 510)
Consider what you have read about respiratory structures in mammals. At the end of this unit you will dissect a fetal pig to observe the structures of a typical mammalian respiratory system.

The major organs of the respiratory system are a pair of lungs. Lungs fulfill the first three structural requirements of a respiratory system: they provide a respiratory membrane, a large surface area, and a good supply of blood. The lungs are enclosed within the thoracic, or chest, cavity and are protected by the rib cage.

Air from the outside enters the respiratory system through the nose and mouth. The air is warmed and moistened in the nasal passages and mouth before it travels to the lungs (**Figure 1**). This prevents damage to the thin, delicate tissue of the respiratory membrane. The nasal passages are lined with tiny hairs and mucus that filter out and trap dust and other airborne particles, preventing them from entering the lungs.

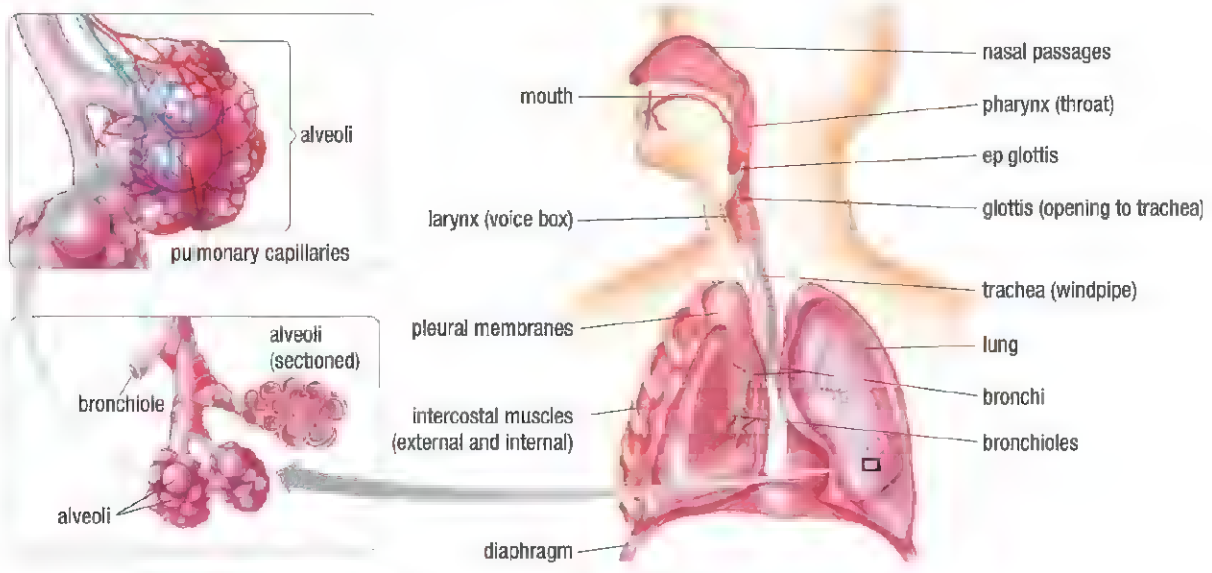


Figure 1 The human respiratory system

The air then travels from the mouth or nasal passages into the pharynx. Recall from the previous chapter that during swallowing, the epiglottis closes the glottis, the entrance to the trachea, so that food goes into the esophagus. During breathing, however, the glottis remains open so that air flows into the trachea, or windpipe. The **trachea** is a semi-rigid tube of soft tissue wrapped around c-shaped bands of cartilage. These bands of cartilage are necessary to keep the trachea open. The walls of the trachea are lined with mucus producing cells and cilia, which further protect the lungs from foreign matter (**Figure 2**). The mucus is sticky and traps dust and other particles. Cilia are tiny hair-like structures that are found on some cells. The wave-like motions of the cilia sweep the trapped material upward through the trachea, where it is swallowed or, occasionally, expelled from the body when coughing or sneezing.

trachea the tube leading from the mouth toward the lungs

Figure 2 The trachea is lined with mucus-producing cells and cilia. Mucous cells, coloured red in this scanning electron micrograph (SEM), secrete mucus that traps dust and other airborne particles. The cilia, coloured pink, sweep the trapped material out of the trachea. *Magnification 5000 ×.*

The trachea branches into two **bronchi** (singular: bronchus). Each bronchus connects to a lung. Inside the lungs, the bronchi branch repeatedly into smaller and smaller tubes called **bronchioles** to form a respiratory tree. The airways end in clusters of tiny sacs called **alveoli** (singular: alveolus) (Figure 1, page 440). Each cluster of alveoli is surrounded by a network of capillaries, which are extremely small blood vessels. Each alveolus is tiny, measuring only 0.1 μm to 0.2 μm (micrometres) in diameter. It is the sheer number of alveoli, approximately 150 million in each lung, that provides the necessary surface area for gas exchange. If the entire surface area inside the lungs were flattened out, it would cover an area about the size of a tennis court!

bronchus one of the two main branches of the trachea that lead toward the lungs

bronchiole a tiny branch of a bronchus that connects to a cluster of alveoli

alveolus a tiny sac at the end of a bronchiole that forms the respiratory membrane

GAS EXCHANGE IN THE ALVEOLI

By the time air reaches the alveoli, it is at normal body temperature, around 37 °C, and is saturated with moisture. The respiratory membrane that forms the alveoli is also moist. This moisture is critical because oxygen cannot diffuse across the respiratory membrane unless it is dissolved in a liquid.

The alveoli are perfectly adapted for gas exchange. The respiratory membrane is extremely thin (one cell layer thick), so that there is little distance between the air in an alveolus and the blood in the capillaries that surround the alveolus (**Figure 3**). Oxygen and carbon dioxide can easily diffuse across the respiratory membrane. The network of capillaries encapsulates the alveoli so that there is an adequate supply of blood for the oxygen to diffuse into and the carbon dioxide to diffuse from.

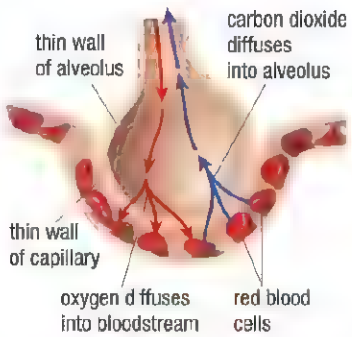


Figure 3 Only two cell layers separate the air in the alveolus from the bloodstream.

The Mechanism of Ventilation

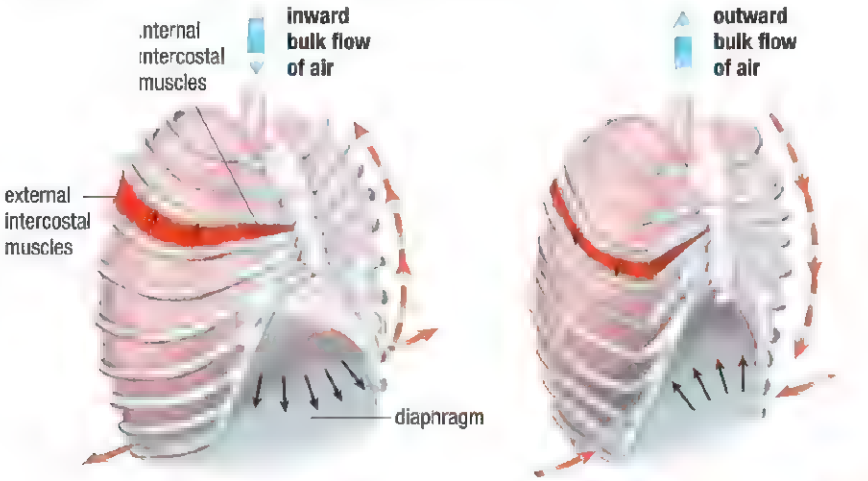
As you have learned, the lungs fulfill three of the important structural features of the human respiratory system: a thin permeable respiratory membrane, a large surface area for gas exchange, and a good supply of blood. The mechanism of ventilation fulfills the fourth important structural feature: a breathing system for bringing oxygen-rich air to the respiratory membrane.

Ventilation, or breathing, is based on the principle of negative pressure. When the air pressure inside the lungs is lower than the atmospheric pressure, air is forced into the lungs. Conversely, when the air pressure inside the lungs is higher than the atmospheric pressure, air is forced out of the lungs. Air always flows from an area of higher pressure to an area of lower pressure. What creates these pressure differences?

diaphragm a large sheet of muscle located beneath the lungs that is the primary muscle in breathing

external intercostal muscle a muscle that raises the rib cage, decreasing pressure inside the chest cavity

The thoracic cavity is separated from the abdominal cavity by a large dome-shaped sheet of muscle called the **diaphragm**. During inhalation, the breathing control mechanisms in the brain cause the diaphragm to contract. This contraction shortens and flattens the diaphragm. At the same time, the **external intercostal muscles**, located between each rib, contract and pull the ribs upward and outward. These two actions together increase the volume of the thoracic cavity and reduce the pressure inside the lungs. Because the atmospheric pressure is greater than the pressure in the thoracic cavity, air rushes into the lungs to equalize the pressure (**Figure 4(a)**). The lungs fill with air, stretching and expanding like balloons.



(a) Inhalation
Diaphragm and external intercostal muscles contract, expanding the chest cavity. Air pressure inside the lungs is reduced, and air flows into the lungs.

(b) Exhalation
Relaxation of the diaphragm and external intercostal muscles. Air pressure inside the lungs increases, and air is forced out of the lungs

Figure 4 Ventilation in the human respiratory system

During normal exhalation, the diaphragm relaxes and returns to its regular domed shape (**Figure 4(b)**). This relaxation of the diaphragm pushes up on the lungs. The external intercostal muscles also relax and the ribs fall and return to their resting position. The air pressure inside the lungs is now greater than the atmospheric pressure, and air is forced out of the lungs. Like inflated balloons, the elasticity of the lung tissue causes the lungs to return to their resting size, which also helps to force air out.

internal intercostal muscle a muscle that pulls the rib cage downward, increasing pressure inside the chest cavity

During strenuous exercise or forced exhalation, a second set of intercostal muscles, called the **internal intercostal muscles**, start contracting and relaxing. When they contract, they pull the rib cage downward, increasing the pressure inside the lungs and forcing more air out of the lungs.

The movement of the lungs within the thoracic cavity might cause a friction problem if it were not for the pleural membranes. **Pleural membranes** cover the lungs and line the thoracic cavity. The space between the pleural membranes is called the pleural cavity. The pleural cavity is filled with fluid to prevent the membranes from separating and also to allow them to slide past each other easily. (Think about how two microscope slides stick together when they are wet. You cannot pull them apart directly; the only way to separate them is to slide them apart.) If air is introduced into the pleural cavity, such as in a stabbing or when a broken rib punctures the lung, then the membranes separate. This causes the lung to collapse, a condition known as a **pneumothorax** (**Figure 5**). In this situation, the rib cage can move but the lung cannot inflate because nothing is pulling on it to increase its volume and reduce its air pressure. This painful condition is characterized by sharp chest pain and breathing difficulty.

pleural membrane a thin layer of connective tissue that covers the outer surface of the lungs and lines the thoracic cavity

pneumothorax a collapsed lung caused by the introduction of air between the pleural membranes

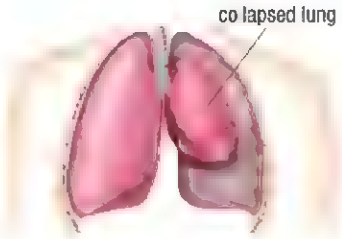


Figure 5 Air introduced into the pleural cavity causes the lung to collapse.

Lung Capacity

The volume of air in the lungs can vary depending on the circumstances. Strenuous physical activity will automatically increase not only the rate of your breathing, but also the depth of your breathing—you inhale and exhale a greater volume of air than during your normal breathing.

Total lung volume depends on sex, body type, and lifestyle. On average, males, non-smokers, and athletes have larger lung volumes than females, smokers, and non-athletes, respectively. The **total lung capacity** is the maximum volume of air that can be taken into the lungs during a single breath. During normal, involuntary breathing, we use only a small fraction of the total capacity of our lungs. This quantity is called the **tidal volume** and is about 0.5 L in the average adult. Normal breathing does not involve a complete exchange of the air in the lungs.

After a normal inhalation, there is room for considerably more air in the lungs. The **inspiratory reserve volume** is the amount of additional air that can be inhaled after a normal inhalation. Similarly, after a normal exhalation, there is still a considerable volume of air left in the lungs. This additional volume of air, called the **expiratory reserve volume**, can be exhaled after a normal exhalation. Even after the expiratory reserve volume has been expelled, the lungs are not completely empty. There is still a volume of air, called the **residual volume**, which prevents the lungs from collapsing.

During periods of high demand for oxygen, the reserve volumes decrease and tidal volume increases. The maximum tidal volume is called the **vital capacity** (**Figure 6**). Because of differences in average lung size, the vital capacity is about 4.4 L to 4.8 L in males and 3.4 L to 3.8 L in females.

total lung capacity the maximum volume of air that can be inhaled during a single breath

tidal volume the volume of air inhaled or exhaled during a normal, involuntary breath

inspiratory reserve volume the volume of air that can be forcibly inhaled after a normal inhalation

expiratory reserve volume the volume of air that can be forcibly exhaled after a normal exhalation

residual volume the volume of air remaining in the lungs after a forced exhalation

vital capacity the maximum amount of air that can be inhaled or exhaled

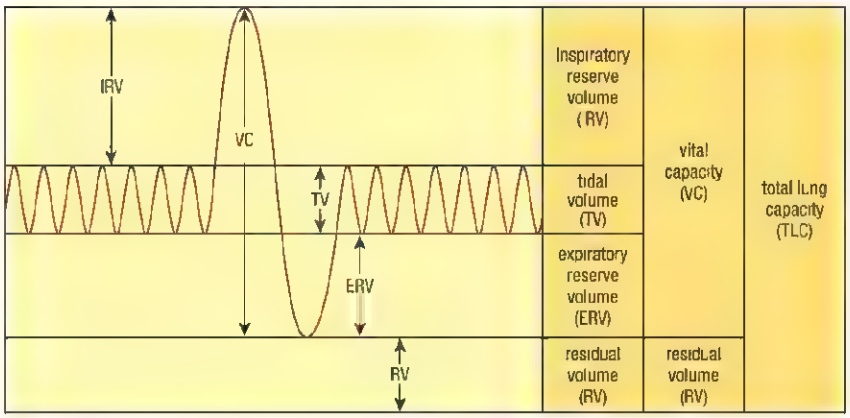


Figure 6 In this graph, each small wave represents the volume changes during a normal breath. For most of our lives, we use only a small proportion of our lung capacity. The tidal volume in normal breathing is approximately 10 % of the total lung capacity. The big wave represents the vital capacity, or a maximum inhalation and exhalation.

Investigation 10.2.1

Determining Lung Volume and Oxygen Consumption (page 465)

Now that you have read about lung capacity, you can perform Investigation 10.2.1.

In this observational study you will use a spirometer to measure your tidal volume and vital capacity. Using this information, you will determine your reserve volumes. You will also determine your oxygen consumption.

Oxygen Usage

Physical activity depends on the energy released during aerobic cellular respiration, and this, in turn, depends on the amount of oxygen and how quickly it is supplied. The maximum rate at which oxygen can be used in aerobic cellular respiration is an indicator of the efficiency of a respiratory system—a high maximum rate of oxygen usage indicates an efficient respiratory system.

VO_2 an estimated or measured value representing the rate at which oxygen is used in the body, measured in millilitres per kilogram per minute

VO_2max the maximum rate at which oxygen can be used in an individual, measured in millilitres per kilogram per minute

The rate at which oxygen is used in the body, known as **VO_2**, is a function of the amount of oxygen delivered to the body in a given time. The maximum amount of oxygen that an individual can use during sustained, intense physical activity is called the **VO_2max**. VO_2 and VO_2max are both measured in millilitres of oxygen per kilogram of body mass per minute (mL/kg/min). **Table 1** provides a range of VO_2max values for males and females of different ages at different efficiency levels.

Table 1 VO_2max Norms for Men (M) and Women (F) (mL/kg/min)

Age	M/F	Very poor	Poor	Fair	Good	Excellent	Superior
13–19	M	<35.0	35.0–38.3	38.4–45.1	45.2–50.9	51.0–55.9	>55.9
	F	<25.0	25.0–30.9	31.0–34.9	35.0–38.9	39.0–41.9	>41.9
20–29	M	<33.0	33.0–36.4	36.5–42.4	42.5–46.4	46.5–52.4	>52.4
	F	<23.6	23.6–28.9	29.0–32.9	33.0–36.9	37.0–41.0	>41.0
30–39	M	<31.5	31.5–35.4	35.5–40.9	41.0–44.9	45.0–49.4	>49.4
	F	<22.8	22.8–26.9	27.0–31.4	31.5–35.6	35.7–40.0	>40.0
40–49	M	<30.2	30.2–33.5	33.6–38.9	39.0–43.7	43.8–48.0	>48.0
	F	<21.0	21.0–24.4	24.5–28.9	29.0–32.8	32.9–36.9	>36.9
50–59	M	<26.1	26.1–30.9	31.0–35.7	35.8–40.9	41.0–45.3	>45.3
	F	<20.2	20.2–22.7	22.8–26.9	27.0–31.4	31.5–35.7	>35.7
60+	M	<20.5	20.5–26.0	26.1–32.2	32.3–36.4	36.5–44.2	>44.2
	F	<17.5	17.5–20.1	20.2–24.4	24.5–30.2	30.3–31.4	>31.4

Investigation 10.2.2

The Relationship between Long-Term Exercise and Vital Capacity (page 467)

Now that you have read about lung capacity, you can perform Investigation 10.2.1.

In this correlational study you will analyze data to identify the potential relationships between exercise and vital capacity.

WEB LINK

For information on methods of determining VO_2max,

GO TO NELSON SCIENCE

VO_2 and VO_2max can be calculated using a spirometer. A spirometer directly measures the volume of air that is taken into the lungs. A spirometer also calculates the rate at which oxygen is used by taking into account the breathing rate and body mass (**Figure 7**). There are also indirect methods that provide fairly accurate estimates of VO_2 and VO_2max.

Figure 7 A spirometer measures the volume of oxygen used while exercising at maximum capacity. The VO_2max for the individual can be determined using this measurement.

Respiratory Structures in Fish

Most aquatic organisms obtain oxygen from the water that surrounds them, so their respiratory structures are considerably different from those of humans and other mammals. The respiratory system in many aquatic animals (including fish, clams, marine worms, and crayfish) involves gills. Gills are extensions of the body surface. They are folded and branched structures that provide a maximum surface area through which oxygen can be absorbed and carbon dioxide removed.

In bony fish, the gills are located underneath a protective, bony flap at the side of the head. The movement of the mouth and bony flap in some fish helps move water through the mouth and over the gills (**Figure 8**). This ensures a constant supply of oxygen-rich water to the gills. Some cartilaginous fish, such as the great white shark, have to swim continuously to ensure that water is flowing over their gills.

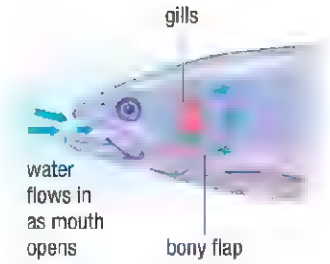


Figure 8 Water enters the fish's mouth and exits through the gill slits.

Fish gills are made up of several gill arches, which are made up of rows of feathery gill filaments. Within the filaments is a rich network of capillaries (**Figure 9(a)**). In the gill filaments, blood flows through the capillaries in the opposite direction to the flow of oxygen-rich water over the filaments (**Figure 9(b)**).

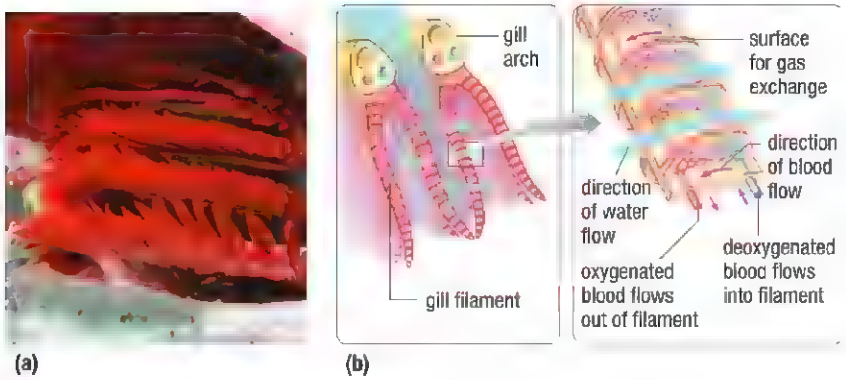


Figure 9 (a) Fish gills appear red because of the rich blood supply flowing through the thin filaments. (b) As water flows over the gills, oxygen diffuses from the water into the blood vessels and carbon dioxide diffuses from the blood into the water.

This process, known as countercurrent exchange, maximizes the amount of oxygen that diffuses into the blood (**Figure 10**). Since the blood and water move in opposite directions, blood with a lower oxygen concentration is always adjacent to water with a higher oxygen concentration. When the difference in oxygen concentration is greater, more oxygen diffuses from the water to the blood. At the same time that oxygen diffuses into the blood, carbon dioxide diffuses out.

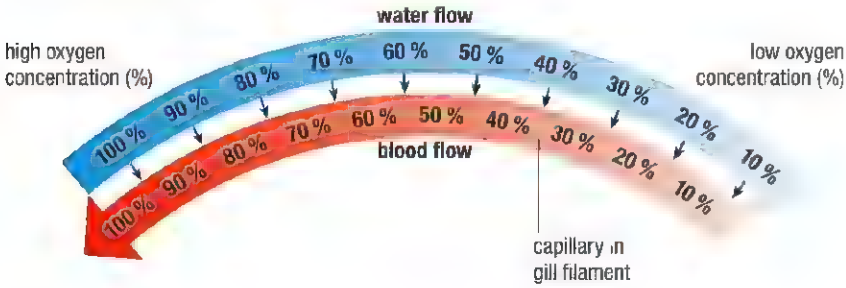


Figure 10 The oxygen concentration of water decreases as the water flows over the gills and oxygen diffuses into the blood. The oxygen concentration of blood increases as the blood flows against the flow of the water.

UNIT TASK BOOKMARK

Consider what you have learned about the structures and functions of the respiratory system, in particular lung capacity and oxygen usage. How can this information he p you as you complete the Unit Task?

10.2 Summary

- The respiratory system, along with the circulatory system, is responsible for delivering oxygen to, and removing carbon dioxide from, each cell of the body.
- In the human respiratory system the lungs provide the large surface area through which oxygen and carbon dioxide diffuse.
- Lung ventilation depends on negative pressure. Negative pressure is created in the lungs when the diaphragm and external intercostal muscles contract to increase the volume of the lungs, sucking air into the lungs. When the diaphragm and external intercostal muscles relax, volume decreases and air pressure increases, forcing air out of the lungs.
- The volume of air used in normal breathing, called the tidal volume, is only a small fraction of the total capacity of the lungs.
- VO_2 is the rate at which oxygen is used by the body. It can be determined from direct measurements or estimated by indirect methods. The maximum amount of oxygen that can be used by the body is called VO_2max.
- Fish and many other aquatic animals have gills that are adapted to obtaining oxygen from water.

10.2 Questions

1. What is the primary function of the respiratory system? K/U
2. (a) Use a simple labe led diagram to describe the structure of the human respiratory system.
   (b) Explain the model you made in the Mini Investigation on page 437 by matching the parts and functions of your model with the structures and functions of the human respiratory system. K/U C A
3. The human resp ratory system has a number of built-in safety features to protect the lungs from foreign matter. Describe these features and explain how they protect the lungs. K/U T/I
4. What physical characteristics of the alveoli make them ideal structures for gas exchange? Explain why. K/U T/I A
5. Describe and explain how negative pressure works in the human respiratory system. K/U A
6. A pneumothorax can be caused by a trauma to the rib cage or a number of other factors. Use the Internet and other sources to research other conditions that might cause a pneumothorax. Write a brief report on the causes, symptoms, diagnosis, and treatments of a pneumothorax. T/I C
7. Describe and explain the responses in the resp ratory system when you start to exercise. K/U A
8. Explain the difference between total lung capacity and vital capacity. K/U A
9. During normal breathing, only a small proportion of the total lung capacity is used. How is this a survival feature? K/U T/I A
10. Why do you think mass (kg) is included in the unit for VO_2 and VO_2max (mL/kg/min)? K/U T/I
11. Examine **Figure 11**, which shows how oxygen would diffuse from water to blood if both water and blood were flowing in the same direction. Compare this with gas exchange in fish, where blood flows in the opposite direction of water flow over the gills.

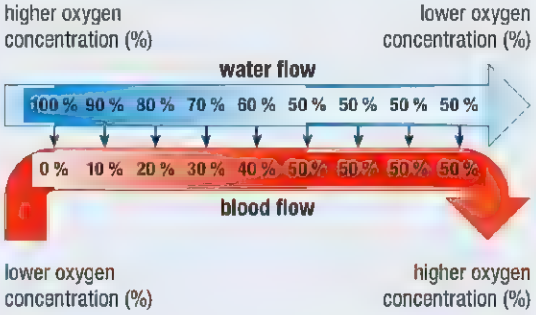


Figure 11

(a) Is the countercurrent system in fish or the system shown in Figure 11 more efficient at transferring oxygen into the blood?
(b) What would happen to oxygen uptake across a fish gill if blood flow continued but all water flow stopped? Explain your reasoning. K/U T/I A

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Transport and Diffusion of Gases

10.3

Our lives depend on the ability to extract oxygen from the air we breathe and to get rid of carbon dioxide waste. Two main factors determine this ability: the surface area of the respiratory membrane and the differences in concentration of gases across the membrane. As you learned in Section 10.2, the membrane that forms the millions of alveoli in the lungs provides the surface area. In this section you will examine the second factor affecting gas exchange—the concentration of the gases on each side of the respiratory membrane.

The Air We Breathe

Earth is surrounded by a thin envelope of air, the atmosphere. The air is most dense at sea level. At high altitude, a given volume of air contains fewer air molecules than it does at sea level. In other words, as altitude increases, the concentration or density of air molecules decreases. As density decreases, air pressure also decreases (**Figure 1**).

The SI unit for pressure is the pascal (Pa). A pascal is a force of one newton exerted on an area of one square metre. Since the pascal is a very small quantity, pressures are often measured in kilopascals (kPa). At sea level, air pressure is 101.3 kPa. At the top of Mount Everest, about 8850 m above sea level, the air pressure drops to about 31 kPa.

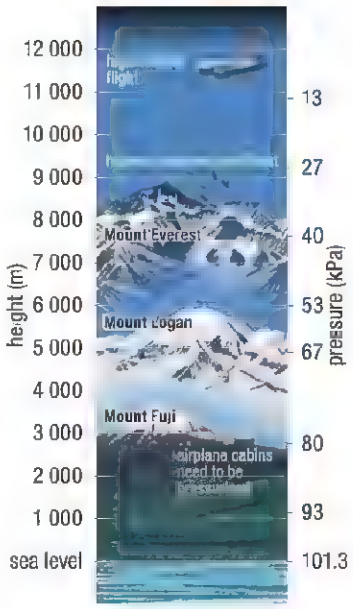

Figure 1 Air density and air pressure decrease with altitude. This means that there are fewer oxygen molecules in a given volume of air at higher altitudes.

Partial Pressures

Although air density and air pressure change at different altitudes, the composition of gases that make up air does not change significantly from sea level to the upper levels of the atmosphere. The proportions of the various gases remain approximately the same.

The air that we breathe is a mixture of gases, but for the purposes of this chapter we are concerned with only two—oxygen and carbon dioxide. Oxygen makes up about 20.9 % of the air in the atmosphere, and carbon dioxide makes up 0.0391 %.

The total air pressure of a mixture of gases is equal to the sum of the **partial pressures** of its component gases. For example, atmospheric pressure at sea level is 101.3 kPa. Since oxygen constitutes 20.9 % of the atmosphere, the partial pressure of oxygen is 20.9 % of the atmospheric pressure at sea level—20.9 % of 101.3 kPa, or 21.17 kPa. Similarly, the partial pressure of carbon dioxide is 0.0397 kPa. The partial pressure of oxygen is written as P_{O_2} and the partial pressure of carbon dioxide is written as P_{CO_2}.

partial pressure the pressure of each of the individual gases that make up the total pressure of a mixture of gases

The concept of partial pressures also applies to gases that are dissolved in liquids. You are likely familiar with what happens when you open a bottle or can of pop. You hear a hissing noise as gas escapes, and you see bubbles rising through the liquid (**Figure 2**). The gases stay in solution as long as the liquid is under pressure. After the pop bottle is opened, the carbon dioxide will continue to escape from the pop until the partial pressure of the carbon dioxide in the pop is the same as the partial pressure of the carbon dioxide in the air above it.

Figure 2 Gases dissolved in liquids stay in solution while the liquid is under pressure.

Partial pressures of gases affect gas exchange. Gases will diffuse across a membrane from an area of higher pressure to an area of lower pressure until the pressures are equal. The greater the pressure gradient, the higher is the rate of diffusion.

OXYGEN TRANSPORT AND DIFFUSION

Partial pressure helps to explain how oxygen diffuses in the lungs. Oxygen moves from the air in the alveoli into the bloodstream, where the partial pressure of oxygen (P_{O_2}) is lower. The P_{O_2} in the alveoli is about 13.3 kPa, which is less than the P_{O_2} of the external surrounding air. This is because some residual or stale air remains in the alveoli, reducing the overall proportion of oxygen. At 13.3 kPa, the P_{O_2} in the alveoli is considerably higher than the P_{O_2} of the blood in the capillaries surrounding the alveoli, which is about 5.33 kPa (**Figure 3(a)**). This significant pressure gradient causes oxygen to diffuse from the air in the alveoli into the liquid component of blood, called **plasma**.

plasma the liquid component of blood in which blood cells are suspended

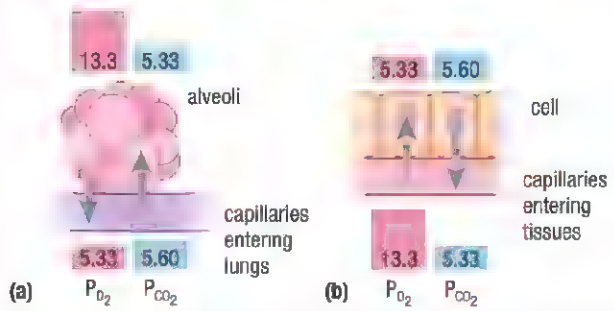

Figure 3 (a) The P_{O_2} in the alveoli is higher than the P_{O_2} in the capillaries surrounding the alveoli, so oxygen diffuses from the air in the alveoli into the blood. Conversely, the P_{CO_2} in the capillaries is higher than the P_{CO_2} in the alveoli, so carbon dioxide diffuses from the blood in the capillaries to the air in the alveoli. (b) Oxygen diffuses from the blood into the tissue cells, and carbon dioxide diffuses from the tissue cells into the capillaries due to the differences in partial pressures.

A constant supply of oxygen is needed by all cells of the body because the cells continuously use oxygen for aerobic cellular respiration. The circulatory system transports oxygen to the body cells in two different ways: attached to hemoglobin molecules within red blood cells (98.5 %) and dissolved in blood plasma (1.5 %). **Hemoglobin** is an iron-containing protein in red blood cells that binds with molecules of oxygen to form oxyhemoglobin. Oxyhemoglobin gives oxygenated blood its bright red colour. Deoxygenated blood is dark red. Blood without hemoglobin carries only about 0.3 mL of oxygen per 100 mL of blood, while blood with hemoglobin carries about 20 mL of oxygen per 100 mL of blood. Hemoglobin increases the blood's capacity to carry oxygen by nearly 70 times!

hemoglobin the protein in red blood cells that bonds with oxygen and enables the transport of oxygen around the body

LEARNING TIP

Blue Blood

Deoxygenated blood in veins is dark red but it appears blue. This is because only the higher-energy blue wavelengths of the visible spectrum can penetrate through the skin and fat covering the vein. The other lower-energy wavelengths are absorbed. The reflection of the blue wavelengths gives veins their characteristic blue colour.

When oxygen-rich blood reaches the body's tissue cells, first the oxygen dissolved in blood plasma diffuses into the tissue fluid, and then into the tissue cells. This diffusion of oxygen reduces the P_{O_2} in the blood plasma. As a result, the oxygen molecules that are attached to hemoglobin in the red blood cells separate from the hemoglobin molecules. These oxygen molecules diffuse into the blood plasma, then into the tissue fluid, and finally into the tissue cells. However, the supply of oxygen in the hemoglobin is not depleted before the blood flows away from the tissues. The P_{O_2} in the veins is 5.33 kPa, so there is still a considerable amount of oxygen in the blood as it moves from the tissues to the heart and on to the lungs. Under normal conditions, blood always contains some oxygen, although much more after it passes through the lungs. This is why you can hold your breath for a short time and not die.

CARBON DIOXIDE TRANSPORT AND DIFFUSION

Carbon dioxide is produced in the body cells as a by-product of aerobic cellular respiration and must be removed. As aerobic cellular respiration continues, carbon dioxide accumulates in cells and diffuses from the cells into the tissue fluid. Under normal conditions, the P_{CO_2} of tissue fluid is 5.60 kPa. This is higher than the P_{CO_2} in the capillaries, where it is about 5.33 kPa (**Figure 3(b)**, above). This pressure gradient is sufficient for carbon dioxide to diffuse from the tissue fluid into the bloodstream.

Carbon dioxide is transported though the blood in three different ways. About 7 % of the carbon dioxide in the bloodstream remains dissolved in the plasma. Another 20 % attaches to hemoglobin to form carbaminohemoglobin. The rest of the carbon dioxide, about 73 %, reacts with the water in plasma to form carbonic acid. Carbonic acid quickly separates into bicarbonate ions, HCO_3^-, and hydrogen ions, H^+ (**Figure 4(a)** and **(b)**). This creates a problem—the increase of hydrogen ions increases the acidity of the plasma, which can be life threatening.

This problem is solved by hemoglobin. As hemoglobin releases oxygen molecules to the tissue cells, it attaches hydrogen ions, H^+. The attachment of H^+ ions to hemoglobin prevents the dangerous accumulation of these ions in blood and tissue fluid. The bicarbonate ions, HCO_3^-, remain dissolved in the blood plasma and are carried by the bloodstream to the lungs.

In the lungs, the H^+ ions separate from the hemoglobin molecules and diffuse into the blood plasma. The H^+ ions react with the bicarbonate ions in the blood plasma to re-form carbon dioxide and water (**Figure 4(c)**). This is essentially the reverse of the reaction that occurred in the tissues where hemoglobin picked up the H^+ ions. The carbon dioxide molecules produced in this reaction mix with the carbon dioxide molecules that were carried in dissolved form in the plasma. As a result, the P_{CO_2} of the blood in the capillaries surrounding the alveoli is approximately 5.60 kPa. The P_{CO_2} of the air in the alveoli is approximately 5.33 kPa (Figure 3(a), page 448). This difference in the partial pressures of carbon dioxide causes the carbon dioxide to diffuse from the blood plasma into the air within the alveoli. The act of breathing then takes the carbon dioxide–rich air from the alveoli to the external environment.

(a) $CO_2 + H_2O \rightarrow H_2CO_3$

(b) $H_2CO_3 \rightarrow H^+ + HCO_3$

(c) $H^+ + HCO_3 \rightarrow CO_2 + H_2O$

Figure 4 (a) CO_2 produced during aerobic cellular respiration dissolves in the tissue fluid around the cells. This forms carbonic acid (H_2CO_3). (b) Carbonic acid separates into H^+ ions and HCO_3^- ions. (c) These H^+ ions and HCO_3^- ions combine in the red blood cells to form CO_2 and H_2O. The CO_2 is released into the air in the alveoli.

The Effect of Altitude on Respiration

The respiratory system faces challenges at high altitudes. The atmospheric pressure at 2000 m is about 80 kPa. At 7000 m, the atmospheric pressure is only 40 kPa. Above 7000 m, the atmospheric pressure is so low that humans cannot survive. The reason is that even though oxygen still constitutes 20.9 % of the air, the density and partial pressure of oxygen are too low—there are not enough oxygen molecules in a given volume of air. A breath of air at high altitude contains fewer oxygen molecules than the same breath of air at sea level.

The partial pressure of oxygen in the air at 2000 m is 20.9 % of 80 kPa, or about 17 kPa. This is significantly lower than the P_{O_2} of air at sea level. The pressure gradient between the P_{O_2} of the air and the P_{O_2} of the blood is reduced, so the rate of diffusion across the respiratory membrane decreases, and the supply of oxygen to the body is reduced. Depending on the altitude, the decreased oxygen supply can cause altitude sickness. The symptoms of altitude sickness include shortness of breath, headache, dizziness, tiredness, and nausea.

Over time, when the supply of oxygen is reduced, the kidneys increase the secretion of a substance called erythropoietin (EPO). EPO is a hormone that stimulates the production of red blood cells. Increasing the number of red blood cells increases the amount of oxygen that can be absorbed from the air and delivered to the body cells. Some endurance athletes, such as long-distance runners and triathletes, train at high altitudes to increase the number of red blood cells (**Figure 5**). Training at a high altitude for just a few weeks can increase the red blood cell count from about 5 000 000/mL to about 7 000 000/mL. Since the lifespan of red blood cells is between 90 and 120 days, the additional red blood cells will remain active for several weeks afterward, giving athletes an extra reservoir of oxygen. Recent studies have suggested that although living at high altitudes provides benefits for endurance athletes, training at high altitudes may not. One of the newer techniques involves sleeping or resting at a high altitude and moving to a lower altitude to train.

Although EPO is a naturally occurring substance that is produced in the human body, the synthetic version (which is virtually identical to the natural substance and is used to treat anemia) is a banned substance in competitions such as the Olympic Games. A new urine test is available that can distinguish between natural and synthetic EPO.

Figure 5 Training at high altitudes may provide a legal competitive advantage because of the additional red blood cells that the body produces naturally.

The Control of Breathing

Breathing is largely an involuntary action. It is controlled by the coordinated efforts of the nervous system and the circulatory system. The normal rhythmic movements of inhalation and exhalation are controlled by signals from the respiratory centre in the brain stem (**Figure 6**). The brain sends out signals that cause the diaphragm and external intercostal muscles to contract, causing inhalation. Stretch receptors in the lungs send signals back to the brain, indicating that the lungs have expanded. The brain then stops signalling the diaphragm and intercostal muscles, causing them to relax and bringing about exhalation. We can consciously override these signals for a short period, such as when we intentionally hold our breath, talk, or sing. This override is controlled by other centres in the brain.

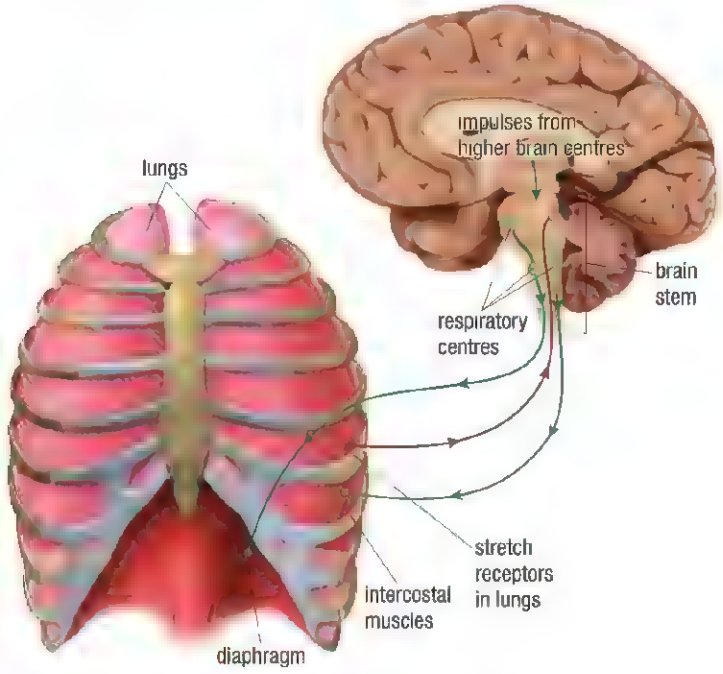

Figure 6 Another example of the interdependence of organ systems can be seen in the contraction and relaxation of the muscles that enable breathing. These muscles are controlled by the respiratory centre in the brain stem.

Maintaining Oxygen and Carbon Dioxide Levels

The rate of breathing is determined by the demand for oxygen or the need to eliminate carbon dioxide. But how does the body know when there is insufficient oxygen or too much carbon dioxide? The levels of oxygen and carbon dioxide in the blood are continuously monitored by chemical receptors in the brain itself, in the arteries leading to the brain, and in the arteries leaving the heart.

The first and most significant effect on breathing is the level of carbon dioxide. An increase in aerobic cellular respiration increases the amount of carbon dioxide in the blood, which in turn produces carbonic acid and lowers the pH of the blood. Receptors in the brain detect the decrease in pH and recognize this as a sign that carbon dioxide levels are too high. There are also chemical receptors in the arteries in the neck and the arteries leaving the heart that are sensitive to the pH of the blood. A decrease in the pH will trigger a signal to the respiratory centre in the brain. In response, the brain sends out signals that increase both the breathing rate and the volume of inhalation by causing the diaphragm and intercostal muscles to contract more rapidly and more forcefully. The heart rate also increases at the same time, so that oxygen is quickly delivered to the body while additional carbon dioxide is removed.

The monitoring of oxygen levels is a secondary breathing control mechanism and is not as significant as monitoring carbon dioxide levels. Receptors in the arteries monitor the level of oxygen in the blood leaving the heart and going to the brain. However, these receptors will not signal the respiratory centre of the brain to trigger an increase in breathing rate until the oxygen level falls significantly below normal. In most circumstances, the higher carbon dioxide levels will have triggered a response before this happens.

10.3 Summary

- The air that we breathe is a mixture of gases. Oxygen makes up 20.9 % of the atmosphere. Carbon dioxide constitutes only 0.0391 % of the atmosphere.
- The pressure of a mixture of gases is equal to the sum of the partial pressures of the component gases.
- Oxygen and carbon dioxide are exchanged between the interior and exterior of the body by diffusion. These gases will diffuse from an area with a higher partial pressure to an area of lower partial pressure.
- Hemoglobin is an iron-containing protein in red blood cells that binds with molecules of oxygen.
- Carbon dioxide diffuses from cells into the plasma, where it forms carbonic acid. The hydrogen ions make the blood more acidic. Hemoglobin adjusts the pH of the blood by picking up the hydrogen ions and carrying them back to the lungs, where they recombine with bicarbonate ions in the plasma to produce carbon dioxide and water.
- Involuntary breathing is controlled by the respiratory centre in the brain stem. Breathing rate and depth increase if the concentration of carbon dioxide in the blood increases.

UNIT TASK BOOKMARK

Consider what you have learned about how oxygen and carbon dioxide are transported in the human respiratory system. How can this information help you complete Parts A and C of the Unit Task?

10.3 Questions

1. (a) At higher altitudes the air is described as "thinner." Explain what this means.
   (b) Is the composition of air different at different altitudes? Explain.
   (c) How does the partial pressure of oxygen change with altitude? K/U T/I A
2. Why is the partial pressure of carbon dioxide in the blood higher than the partial pressure of carbon dioxide in the atmosphere? K/U T/I A
3. Gas exchange occurs in two locations—the alveoli in the lungs and the body cells. Using the concepts of partial pressures and pressure gradients, explain the gas exchange that occurs at each of these locations. K/U T/I A
4. Describe the roles of hemoglobin in gas exchange. K/U
5. (a) How does the body respond if a person moves to a higher altitude?
   (b) How do athletes use this information? K/U A
6. (a) How is breathing rate regulated?
   (b) How does the respiratory system respond when carbon dioxide levels are too high? How does the circulatory system respond? K/U
7. Use the Internet and other sources to find out why carbon monoxide is a dangerous substance. Write a brief report outlining the causes, physiological effects, treatments, and risks of carbon monoxide poisoning. T/I C A

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10.4 Interference with Gas Exchange

Suppose it is your birthday and your family has just brought your birthday cake to the table. There are 16 lit candles. Even with a great deal of effort, you are only able to blow them out one at a time! You feel out of breath. This might be the situation if you were suffering from a disease of the respiratory system.

Disorders of the Respiratory System

There are numerous diseases and conditions that interfere with the primary function of the respiratory system—the uptake and delivery of oxygen to the body cells and the removal of carbon dioxide. Lung diseases such asthma and bronchitis restrict the flow of air into and out of the lungs, resulting in an inability to deliver sufficient air to the alveoli. Other diseases, such as emphysema, damage or destroy the respiratory membrane in the alveoli. This damage reduces the surface area for diffusion, which, in turn, impairs the process of gas exchange.

Smoke from cigarettes and other tobacco sources is the primary cause of lung disease in Canada. Other causes of lung disease include air pollution and airborne irritants such as asbestos. Regardless of the cause or mechanism, the result is the same: insufficient oxygen is available to the tissues of the body.

Asthma

asthma a chronic respiratory disease characterized by inflammation and swelling of the bronchi and bronchioles that obstructs airflow

Worldwide, asthma is one of the most prevalent respiratory problems and the most common chronic, or frequently recurring, condition in children. In Canada, nearly 10 % of the population suffers from asthma. **Asthma** is a chronic, long-term inflammation of the lining of the bronchi and bronchioles. Inflammation is a protective reaction designed to eliminate some foreign substances or infection. It is characterized by swelling and redness due to increased blood flow to the affected tissue. When the lining of the airways swells, airflow into the lungs is reduced. The inflammation stimulates the overproduction of sticky mucus in the airways, which also contributes to reduced airflow. In most cases, the muscles around the bronchi and bronchioles become sensitive and contract, further narrowing the openings and restricting the airflow (**Figure 1**).

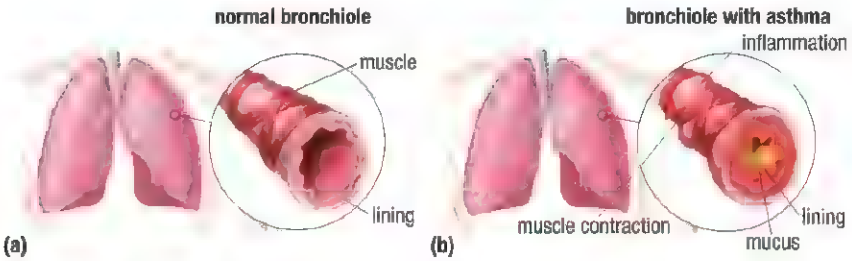

Figure 1 Compared to (a) normal bronchioles, the (b) bronchioles of a person with asthma are severely restricted by inflammation, excess mucus, and muscle contractions.

The symptoms of asthma include coughing, wheezing, tightness in the chest, and shortness of breath. The symptoms and their severity can vary between individuals and can occur intermittently or persistently. A sudden worsening of asthma symptoms is called an asthma attack. Many factors can trigger an asthma attack. These triggers include cigarette smoke, dust, cold air, physical exertion, and allergens such as pollen, pollution, dust mites, and animal dander.

Asthma is not curable but can be managed and treated successfully. Management involves identifying the triggers and avoiding them if possible. In many cases, however, it is virtually impossible to avoid widespread triggers such as pollen or pollution. In these situations, medication becomes necessary.

Medications for asthma include relief medications that open up, or dilate, the bronchi and bronchioles to allow greater airflow. Other medications can reduce the inflammation in the bronchi and bronchioles. Medications are often self-administered using inhalers, commonly called puffers, which deliver a measured dose of the drug directly into the airways and lungs (**Figure 2**). With proper management and medication, most asthma sufferers can lead normal, active lives.

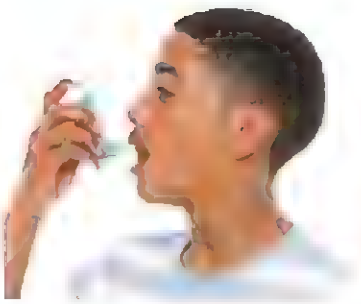

Figure 2 Puffers are used to deliver medications by inhalation.

chronic obstructive pulmonary disease (COPD) a chronic, progressive disease that involves both obstructive bronchitis and emphysema

Chronic Obstructive Pulmonary Disease (COPD)

Approximately 1.5 million Canadians suffer from **chronic obstructive pulmonary disease (COPD)**, and an estimated 1.6 million remain undiagnosed. COPD is a long-term respiratory disease that is a combination of two diseases—bronchitis and emphysema. It is estimated that 80 % to 90 % of all cases of COPD are caused by cigarette smoke, but prolonged exposure to pollution, dust, or fumes can also contribute. Genetic disorders can also cause emphysema, even when other contributing factors, such as smoking, are absent. The symptoms of COPD are very similar to those of asthma: coughing, wheezing, chest tightness, and shortness of breath.

Similar to asthma, bronchitis is an irritation and inflammation of the airways. The linings of the bronchi and bronchioles swell and produce excess mucus, reducing airflow into the lungs.

The other condition of COPD, emphysema, causes permanent damage to the alveoli. The walls between the alveoli are damaged or destroyed, and the alveoli lose their elasticity and shape (**Figure 3**). The result is a reduction in the surface area of the respiratory membrane. Because there is less surface area for gas exchange, the amount of oxygen diffusing into the blood is reduced. Carbon dioxide diffusion is also reduced, causing carbon dioxide levels in the blood to increase. The respiratory system responds by increasing the breathing rate and the heart rate in an attempt to maintain appropriate oxygen and carbon dioxide levels.

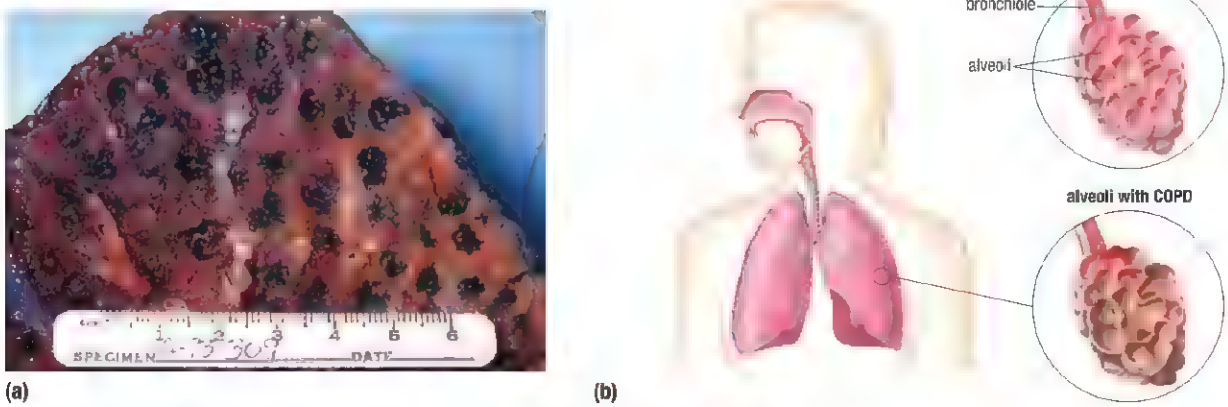

Figure 3 (a) The black spots in the lung are areas where the alveoli are damaged. (b) Compared to normal alveoli, alveoli with COPD are essentially non-functional and significantly reduce the ability of the lung to exchange gases.

There is no cure for COPD. Damage to the alveoli is permanent and generally worsens over time. Proper management, medications, and lifestyle changes can help alleviate the symptoms and slow the progress of the disease. In severe cases, oxygen therapy may be necessary if oxygen levels drop below a critical level. In extreme cases, lung transplants are necessary. People who suffer from COPD are likely to die from it, or from a related complication such as pneumonia, heart failure, or respiratory failure. How long they live depends on many factors, such as age, the extent of lung damage, treatment, and any other health problems.

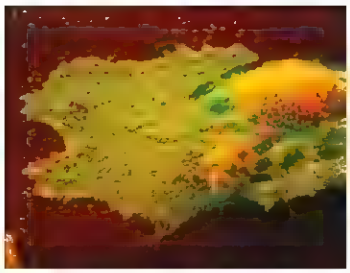

Figure 4 Once inside the body, the influenza virus (small yellow dots) takes over a cell and multiplies rapidly. The virus then spreads to other cells throughout the body.

CAREER **LINK**

Infectious Disease Specialist
The spread of infectious diseases is a concern to health authorities and governments. To find out more about a career as an infectious disease specialist,

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tuberculosis (TB) a bacterial infection that damages the tissues of the lungs and interferes with gas exchange

Respiratory Infections

The respiratory system is probably the most vulnerable part of the human body. The lungs are a prime target for infection because of constant exposure of living tissue to the external environment. Even though safety mechanisms, such as hairs and mucus in the nasal passages and cilia and mucus in the airways, trap most airborne particles, some still enter the farthest reaches of the respiratory system. There are many respiratory infectious diseases caused by viruses and airborne micro-organisms, such as bacteria or fungi.

INFLUENZA

Influenza, commonly known as the flu, is caused by a virus (**Figure 4**). New strains of flu viruses are constantly appearing, often as a result of mutations of existing flu viruses. One well-publicized incidence of a new flu virus is H1N1 in 2009. The flu virus may affect the whole body or be confined to the lungs. Symptoms usually include a fever, dry cough, sore throat, runny nose, and muscle and joint aches and pains. If the infection is diagnosed within the first 24 h to 48 h, antiviral drugs can be administered, reducing the symptoms and shortening the length of the infection. However, most people usually recover without treatment in a week. During this time, the individual is infectious and is able to spread the virus to others.

Influenza is highly contagious. When an infected person coughs or sneezes, he or she sends droplets of moisture carrying the virus into the air. Another person may inhale the airborne virus and become infected. Viruses can also be spread through hand contact with contaminated surfaces such as door knobs. If the person touches their mouth or nose after touching a contaminated surface, the virus can enter the respiratory system.

Viruses can spread quickly from person to person in a community or region, creating an epidemic. If the virus spreads across a continent or globally, it is called a pandemic. Vaccines that prevent infection have been developed for many of the common flu viruses. It takes about six months to develop and test a vaccine, by which time the infection may have already spread.

TUBERCULOSIS

Tuberculosis (TB) is a bacterial infection caused by *Mycobacterium tuberculosis*. Like many other infectious agents, the bacterium is spread through the air when infected people sneeze or cough. The classic symptoms of TB include coughing, chest pain, weight loss, night sweats, and coughing up blood. If untreated, these symptoms generally worsen over time. TB usually affects the lungs but can move from the lungs to affect the nervous system, the bones and joints in the spine, and other parts of the body.

One of the problems with TB is that an infected person may show no obvious symptoms. Specific tests must be performed to confirm the presence of the bacteria. It is estimated that one-third of the world's population is currently infected. In most individuals, the infection remains inactive; unless the immune system is weakened, there is only a 5 % to 10 % chance that an inactive infection will progress to an active infection. The standard treatment is a six-month course of antibiotics. A vaccine has been available since 1921 that is effective in protecting children against TB.

After the introduction of antibiotics in 1948, and their subsequent widespread use, it was thought that TB would disappear. However, TB persists because some strains of the bacterium are resistant to antibiotics and because the antibiotic treatment process is both time-consuming and expensive. There are about 11 million active cases of TB worldwide, mostly in developing countries. The World Health Organization (WHO) estimates that TB kills almost 3 million people annually. In Canada, about 1600 cases of TB are reported annually. The incidence of TB among Aboriginal people in Canada is 30 times as high as that of the non-Aboriginal population. This may be due to socio-economic conditions such as overcrowded homes, poor living conditions, and lack of medical facilities.

PNEUMONIA

Pneumonia is an infection of the lungs caused by bacteria, viruses, or fungi. The infection causes inflammation of the lining of the bronchi, bronchioles, and alveoli. The infection also causes pus and mucus to accumulate in the alveoli, preventing gas exchange (**Figure 5**).

pneumonia an infection of the lungs that causes the alveoli to fill with pus and mucus, preventing gas exchange

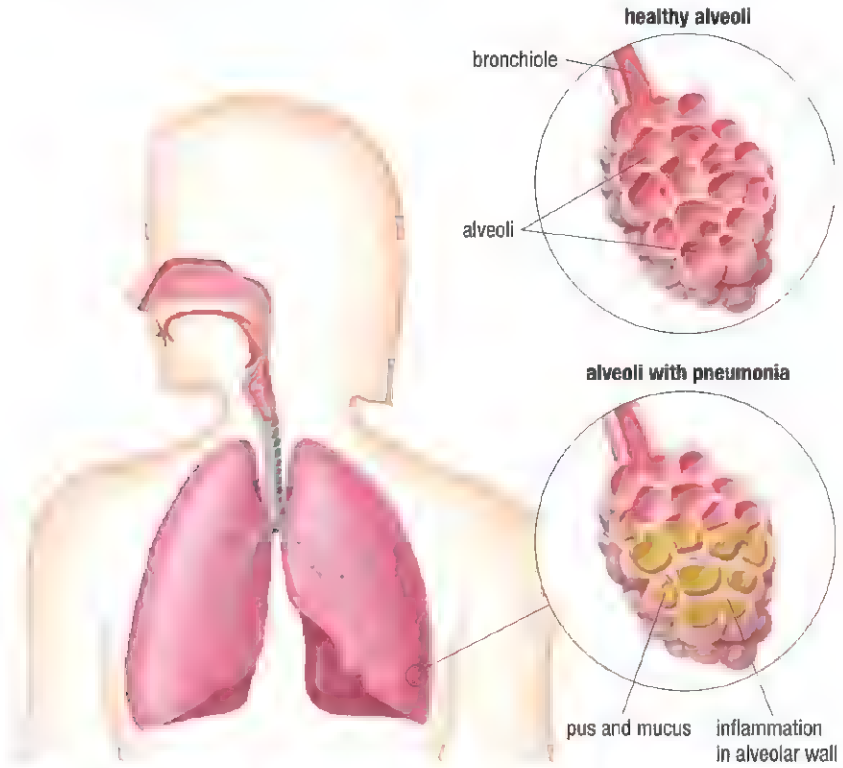

Figure 5 In a person suffering from pneumonia, some alveoli become filled with pus and mucus, preventing gas exchange. Individuals with pneumonia often cough up greenish or yellow mucus from their lungs.

Pneumonia has typical symptoms of an infection and a respiratory disease—fever, cough, and shortness of breath. Pneumonia can be diagnosed by analyzing the mucus in the respiratory system, or phlegm, that is coughed up from the lungs. X-rays can also show if areas of the lungs are blocked with fluids.

Most individuals with healthy immune systems are able to resist or fight off the infection before it progresses. However, pneumonia can be severe or fatal for those with weakened immune systems. For this reason, it is often associated with other long-term illnesses in which the immune system is already compromised. Infants and seniors are also especially susceptible to pneumonia. Bacterial pneumonia can be treated with antibiotics. Before antibiotics existed, pneumonia was fatal for about one-third of those who contracted it. Even with antibiotics and other modern treatments, there is a 5 % fatality rate among those who develop pneumonia.

Cystic Fibrosis

As you read in Chapter 5, cystic fibrosis (CF) is a hereditary disorder in which the gene that influences mucus production is defective. The respiratory system of a person with CF produces unusually thick and sticky mucus that clogs the airways. Like asthma and bronchitis, the airflow to the lungs is reduced. Symptoms include a persistent cough and excess mucus. In 1989 a team of researchers at the Hospital for Sick Children in Toronto, led by Dr. Lap-chee Tsui, discovered the defective gene that causes CF (**Figure 6**).

Figure 6 Dr. Lap-chee Tsui

CAREER LINK

Respiratory Therapist

To find out more about a career as a respiratory therapist,

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CF also makes the individual more susceptible to lung infections. The increased production of mucus in the lungs creates an ideal environment for the growth of bacteria and fungi. CF patients often suffer from persistent lung infections, and much of the treatment of the disease focuses on fighting the infections with antibiotics. Treatment also includes clearing excess mucus from the lungs to help prevent further infections (**Figure 7**). As the disease progresses, lung transplants may become necessary. Many patients with respiratory diseases require ongoing and continuous therapy to alleviate their symptoms and prevent a worsening of the condition.

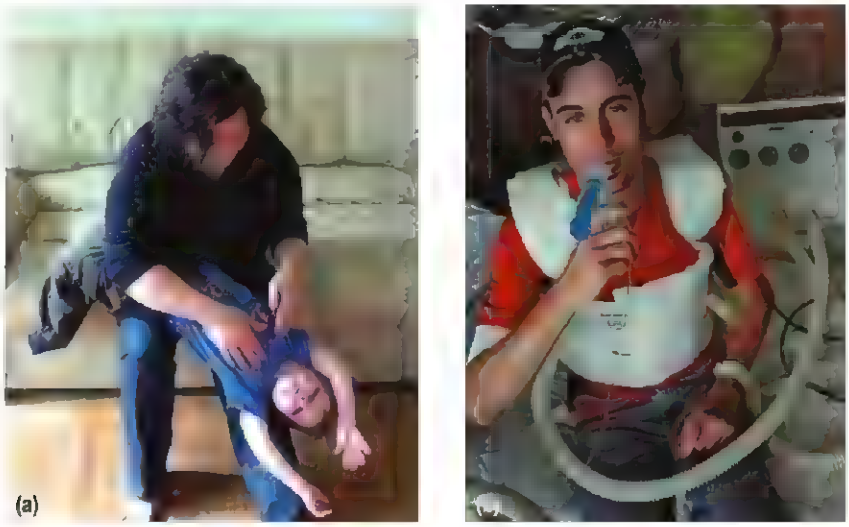


Figure 7 (a) Regular percussion (gentle pounding) of the chest is a standard CF therapy that helps loosen the mucus so that it can be coughed up more easily. (b) A mechanical vest has been developed to simulate the pounding of the chest.

In addition to affecting the respiratory system, CF affects the digestive system. The name of the disease comes from the characteristic fibroid scar tissue that forms in the pancreas. Thick secretions of mucus in the pancreas prevent it from secreting digestive enzymes. Scar tissue in the pancreas can also prevent it from producing insulin, which can lead to a form of diabetes associated only with CF patients.

Like many other inherited characteristics, there are two alleles of the CF gene. As long as one allele for normal mucus production is present, the disease is not expressed. CF occurs when a child receives two recessive, or defective, CF genes, one from each parent. About 4 % of Canadians carry the defective version of the gene responsible for CF, and about one in every 3600 children has CF. Because CF is an inherited disease, genetic testing can identify affected individuals.

In some provinces, including Ontario, all newborns are checked at birth for CF, and about 60 % of diagnoses are made in the first year. The disease gets progressively worse with age, so it is beneficial to begin treatment as early as possible. At present, there is no cure, but major advances have been made in medical knowledge and the development of new treatments. These advances have significantly improved both the quality of life and life expectancy of individuals with CF. Research continues in the area of gene therapy, which holds some promise for a cure. This area of research focuses on replacing the defective gene so that cells in the respiratory system will produce normal mucus.

Effect of Smoking on Gas Exchange

It is well established that smoking is the single greatest cause of respiratory diseases and preventable deaths in the developed world. Smoking is known to cause lung cancer, COPD, bronchitis, emphysema, and asthma. It is also linked to diseases of the circulatory system, such as arteriosclerosis, and heart attacks, which you will learn about in Chapter 11.

Three substances in cigarette smoke cause most of the problems for the respiratory system and the body in general: nicotine, carbon monoxide, and tar. Nicotine is a natural insecticide produced by tobacco plants to kill insect pests. It is an addictive chemical that stimulates the reward pathways in the brain to produce dopamine and endorphins. Dopamine and endorphins are chemicals that act as natural painkillers. The effect of nicotine lasts only about 40 min, and the need for further positive feelings leads to continued smoking to the point of addiction. Unfortunately, nicotine also has many negative effects on the nervous system, such as blocking other chemicals that allow signals to be sent from the brain around the body.

The carbon monoxide from tobacco smoke or from other sources affects the ability of the respiratory system to deliver oxygen to the body cells. Hemoglobin has a much greater tendency to bond with carbon monoxide than it does with oxygen. This means that if carbon monoxide diffuses into the bloodstream, hemoglobin picks it up instead of oxygen, thereby reducing the amount of oxygen delivered to the cells. To make matters worse, the bond between hemoglobin and carbon monoxide is 200 times stronger than the bond between hemoglobin and oxygen, so carbon monoxide does not release from hemoglobin nearly as easily as oxygen does.

Tar is a black, sticky substance that accumulates in the alveoli, effectively preventing any exchange of gases (**Figure 8**). The tar in cigarette smoke is made up of hundreds of different chemicals, many of which are toxic and some of which are carcinogenic, or cancer causing. Some of these chemicals irritate the linings of the airways, causing swelling and increased mucus production. Furthermore, tar causes the cilia on the cells lining the bronchi to become inactive. The cilia do not perform their function of sweeping dust particles and foreign material out of the airways. This can trigger asthma attacks and lead to emphysema.

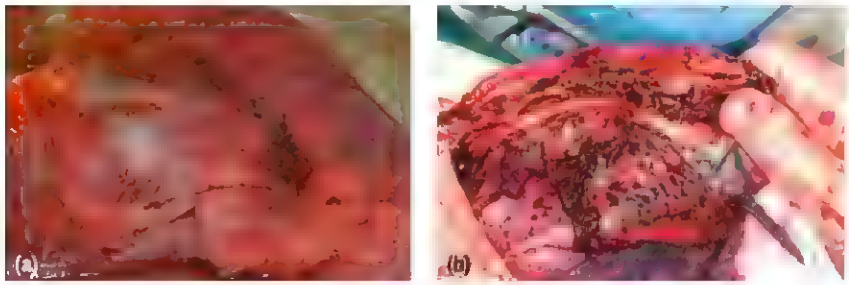


Figure 8 (a) The pink colour of the healthy lungs shows that there is good blood circulation throughout the lungs. (b) The buildup of tar in the lungs as a result of smoking dramatically interferes with the lungs' primary function—the exchange of gases between the body and the environment.

In addition to carbon monoxide and tar, cigarette smoke contains many toxic and likely carcinogenic substances, notably formaldehyde, benzene, and hydrogen cyanide. The carcinogenic chemicals can cause mutations in the genetic material that controls the growth of cells. Cancer results when the damaged cells grow and reproduce too quickly, and form a tumour. **Figure 9** shows a frontal view chest X-ray with a visible cancerous tumor. To confirm an X ray diagnosis, a lung tissue examination such as a biopsy must be performed.

Figure 9 This X-ray reveals a cancerous tumour (red and yellow) in the left lung.

Cancer can originate in the lungs, but it can also spread to the lungs through the circulatory system from tumours in other parts of the body. The tumour invades the tissues of the lungs, replacing normal cells or interfering with the blood flow to the tissues. This reduces the area of the respiratory membrane available for gas exchange and consequently affects the ability to take up oxygen and eliminate carbon dioxide.

UNIT TASK BOOKMARK

Consider what you have learned about respiratory diseases and disorders, as well as the effects of smoking on gas exchange. How can this information help you when you create a health and fitness profile in the Unit Task?

10.4 Summary

- Respiratory system diseases can affect the amount of airflow into the lungs, the process of gas exchange through the respiratory membrane, or both. Many diseases of the respiratory system interfere with the exchange of gases.
- Asthma is the inflammation of the lining of the bronchi and bronchioles, which reduces airflow into the lungs.
- COPD is the inflammation of the airways combined with the permanent destruction of alveoli. The reduced airflow and the damage to the respiratory membrane both contribute to reduced gas exchange.
- Infectious diseases such as influenza, tuberculosis (TB), and pneumonia are caused by viruses or bacteria.
- Cystic fibrosis (CF) is a genetic disorder that affects the respiratory and digestive systems. One of its main symptoms is an overproduction of sticky mucus in the airways; this mucus obstructs airflow to and from the alveoli.
- Cigarette and other tobacco smoke is a primary cause of lung disease. Air pollution and airborne irritants are also contributing factors.
- Carbon monoxide and tar from cigarette smoke cause problems in the respiratory and circulatory systems.

10.4 Questions

1. (a) What is the fundamental problem in most respiratory diseases?
   (b) What are some common symptoms that accompany most respiratory diseases? K/U
2. How is the management of asthma different from the treatment of asthma? K/U
3. A patient suffering from a lung infection was prescribed antibiotics. After seven days of treatment, the condition had not improved. Propose a possible explanation. K/U T/I A
4. Use a T-chart to compare asthma and pneumonia. In your comparison, consider the causes, symptoms, and treatments of each disease. K/U C
5. TB is a serious disease among the homeless, in prison populations, and in developing countries. How might these observations be explained? T/I A
6. In the 1960s, most CF patients did not live to attend elementary school. Today, many are living into their 40s. What accounts for this improvement? K/U A
7. (a) What substances in tobacco smoke cause problems for the respiratory system?
   (b) Explain how each of these substances affects the respiratory system.
   (c) It is well known that smoking has serious health risks. Why do you think people continue to smoke? K/U T/I A
8. Use the Internet and other sources to research ONE of the following topics and write a brief summary: T/I C A
   - the effects of smoking on body systems
   - the current status of TB among Canada's northern Aboriginal populations
   - recent advances in the search for a cure for CF
9. Use the Internet and other sources to research a condition called "the bends." This condition, also known as decompression sickness, is experienced by divers who ascend from their dive too quickly. Prepare a brief report on the cause, symptoms, and treatments of the condition. T/I C

GO TO NELSON SCIENCE

Lung Transplants and Other Technologies

10.5

Not many years ago, lung diseases such as COPD and CF were automatically considered fatal, and life expectancy was relatively short. The progression of the disease would either gradually suffocate the patient or result in other complications that led to death. The emphasis in treatment was on making the patient as comfortable as possible while waiting for the inevitable.

New Technologies

Advances in medical knowledge and in drug and surgical treatments have changed our understanding of respiratory illnesses. These advances have saved the lives of thousands of patients and increased their quality of life and life expectancy.

FLAP Inhibitors

Diseases such as asthma and COPD are known as inflammatory diseases because their symptoms are caused by inflammation of the lining of the respiratory system. When special cells in the immune system detect foreign substances or infectious agents, they release chemicals that cause the characteristic signs of inflammation. These chemicals are produced as part of a complex series of chemical reactions that involve a protein called FLAP (5-lipoxygenase activating protein).

In January 2010, a pharmaceutical company announced that it had just completed a clinical trial of a new drug developed to treat asthma, COPD, and other inflammatory respiratory diseases. This new drug is in a category of drugs known as **FLAP inhibitors**. FLAP inhibitors bind to the FLAP protein, thereby preventing production of the chemicals that cause inflammation.

FLAP inhibitors a category of drugs that interfere with the production of chemicals that cause inflammation

Bronchial Thermoplasty

During an asthma attack, the muscles of the bronchioles contract and decrease the diameter of the airways. This restricts airflow into and out of the lungs. A new procedure, called **bronchial thermoplasty**, reduces the thickness of the muscles surrounding the bronchioles. This procedure results in less constriction of the airways when the muscles contract. Thermoplasty uses thermal energy to reduce the thickness of the muscle. A long, narrow tube, called a catheter, with a wire basket at the end is inserted through a bronchoscope into the lungs (**Figure 1**). (A bronchoscope is a long, thin, flexible—or rigid—tube that has a light and a video camera and is used to examine the bronchi.) The wire basket is expanded until it touches the walls of the bronchiole. Radio-frequency energy is transmitted through the catheter and heats the wire basket and the muscles to about 65 °C. The procedure is repeated along the length of the bronchiole a few millimetres at a time. Normally, three sessions are required to treat all the reachable airways of the lungs.

bronchial thermoplasty a procedure that decreases the amount of constriction of the airways during an asthma attack by using thermal energy to reduce the muscle thickness in the bronchioles

Figure 1 Bronchial thermoplasty reduces the thickness of the muscles in the bronchioles by heating the muscles.

Artificial Lungs

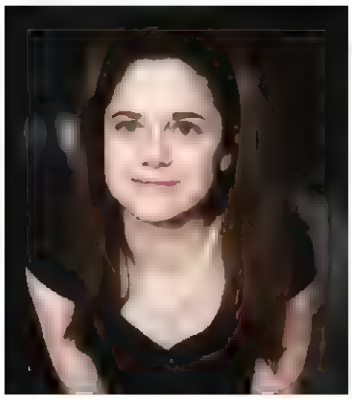


Figure 2 An artificial lung system kept Katie Sutherland alive until donor lungs were available for transplant.

In 2008, Katie Sutherland, a 16-year-old lung transplant patient at Toronto's Hospital for Sick Children, was kept alive by an artificial lung system (**Figure 2**). Katie was waiting for suitable donor lungs for transplant, but she became so sick that her medical team had no choice but to use a new technology that had never been used on a teen before. Doctors connected her to an iLA Membrane Ventilator, an external artificial lung system designed primarily to remove carbon dioxide from the blood. Doctors decided to use the iLA Membrane Ventilator for Katie because she had pulmonary hypertension, which is increased pressure in the blood vessels of the lung. This leads to enlargement of the right side of the heart and heart failure. Once Katie was connected to the device, it reduced the pressure in the pulmonary artery and the failure of the right side of the heart was resolved. The iLA Membrane Ventilator kept Katie alive for a month, until donor lungs became available. You will learn more about hypertension in the circulatory system in Chapter 11.

The iLA Membrane Ventilator is a small device connected to the body by two tubes, usually inserted into the femoral blood vessels, which are in the thigh (**Figure 3**). In Katie Sutherland's case, doctors used the iLA Membrane Ventilator in an innovative manner by connecting the device directly to her heart, between the right ventricle and the left atrium. As blood flows through the device, carbon dioxide diffuses from the blood into a hollow-fibre membrane that acts as artificial alveoli. Although the primary purpose of the device is to remove carbon dioxide, a small amount of oxygen also diffuses through the membrane into the blood, while the patient's lungs also provide some of the required oxygen. The surface of the membrane is treated with heparin. Heparin is a naturally occurring substance that prevents the blood from clotting on the membrane.

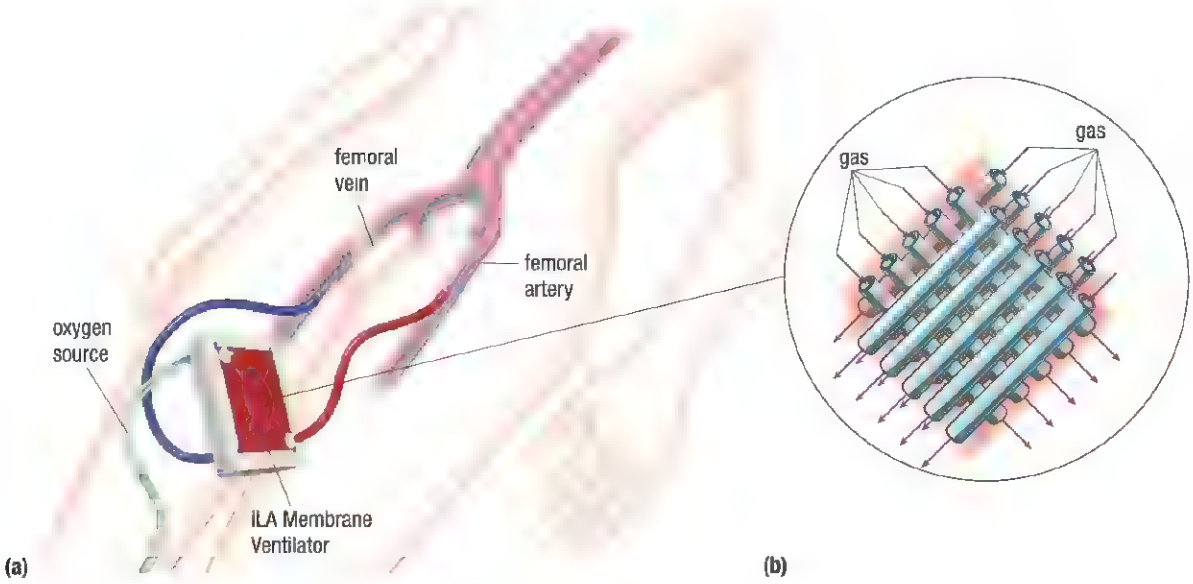


Figure 3 (a) The iLA Membrane Ventilator is a temporary artificial lung system that connects to the body, usually through the two femoral blood vessels. (b) Blood flows over the membrane and carbon dioxide diffuses into the hollow tubes, while a small amount of oxygen diffuses out.

The iLA Membrane Ventilator does not require a pump since it is connected to blood vessels. Blood is pumped through the device by the heart as part of normal circulation. If necessary, a mechanical pump can be used to increase the rate of blood flow and increase the oxygen supply.

Lung Transplants

In some cases, all treatments for diseases such as COPD and cystic fibrosis fail and the disease cannot be controlled. When this happens, the life-or-death option is a lung transplant.

A **lung transplant** involves replacing one or both diseased lungs with healthy lungs from a donor (**Figure 4**). Normally, donor lungs are obtained from a deceased person. The individual must have given prior consent for organ donation, or the family may donate the organs after the individual dies. Depending on the type of disease and the extent of damage to the lungs, it is possible to receive just a portion of a lung. In these cases, a section of lung can be transplanted from a living donor. Two or more living donors are necessary to create a fully functioning lung for the recipient.

lung transplant the surgical procedure of replacing a diseased lung with part or all of a whole healthy lung from a donor

CAREER LINK

Thoracic Surgeon

Some surgeons specialize in thoracic surgery. To find out more about a career as a thoracic surgeon,

GO TO NELSON SCIENCE

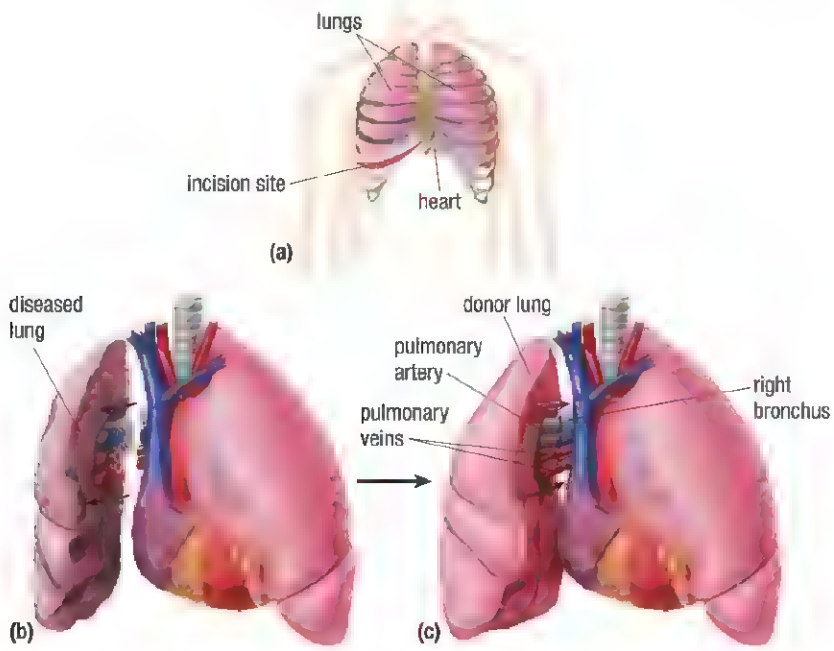


Figure 4 (a) The lung transplant operation takes place through an incision just below the ribs. (b) After the right pulmonary artery and veins are divided and tied off, and the right bronchus is cut, the diseased right lung is removed. (c) The healthy donor lung is put in place, and the blood vessels and bronchus from the lung are connected, restoring the blood and air supply.

Before a lung transplant can take place, the patient must be evaluated to determine if there are any underlying medical conditions that might affect the success of the operation. For example, patients may suffer from cancer, infections, or heart, liver, or kidney problems. Other factors that are also considered include cigarette smoking, substance abuse, and a history of ignoring medical advice.

A donor's blood and tissue type must be a close match to the recipient's for a successful transplant. If they do not match, the recipient's immune system will reject the transplanted organ. There is some degree of rejection in almost all transplants. To prevent or reduce the rejection response, transplant patients are required to take immunosuppressive drugs for the rest of their lives. These drugs suppress the immune system from acting to reject the transplanted organ. However, these drugs pose a significant risk because they suppress the entire immune system, making the patient much more susceptible to infections and other complications.

As with any major surgery, lung transplants involve risks of adverse reactions to medications, bleeding, infections, and blood clots. There are also risks of breathing problems and damage to other organs caused by immunosuppressive drugs. These risks can all affect the success of the transplant and the health of the patient.

Transplant Success and Failure

The first lung transplants were not very successful. Cyclosporine, an immunosuppressive drug, was discovered in 1972 but was not commonly used until the 1980s. After the introduction of cyclosporine, lung transplants became a viable treatment option. Thousands of lung transplants have been performed worldwide since then.

The world's first successful lung transplant was carried out at the Toranto General Hospital, now part of the University Health Network, in Toronto in 1983, followed by the first double-lung transplant in 1986. Since the first transplants, the success rate has climbed significantly. The five-year survival rate for lung transplant patients is now around 60 %, and the number of transplants is increasing. The biggest problem faced by all organ transplant programs is a shortage of donor organs. In Canada, about 40 individuals die each year while waiting for a donor lung.

10.5 Summary

- Advances in scientific knowledge and technology have improved the quality of life and life expectancy of individuals suffering from respiratory diseases.
- FLAP inhibitors are a class of drugs under development that interfere with the production of chemicals that cause inflammation.
- Bronchial thermoplasty eases the symptoms of asthma by reducing the thickness of the muscles in the bronchioles, thereby reducing the constriction of the airways.
- Elimination of carbon dioxide from the bloodstream can be achieved by routing the blood through an artificial external lung. In the artificial lung, gas exchange takes place across a thin membrane of hollow tubes.
- If treatment of respiratory diseases is unsuccessful, a lung transplant may be the only remaining option. During lung transplants, the diseased lung is surgically replaced by a healthy lung from a donor.
- Organ rejection is the greatest risk associated with lung transplants. Immunosuppressive drugs reduce the risk of rejection, but increase the risk of infections.

10.5 Questions

1. Describe the potential of FLAP inhibitors as a treatment for inflammatory diseases. K/U
2. What is bronchial thermoplasty, and how does it help alleviate the symptoms of asthma? K/U T/I A
3. How is the iLA Membrane Ventilator different from actual lungs? What are some advantages and disadvantages of the artificial lung system? K/U A
4. All transplant patients have to take immunosuppressive drugs, yet these drugs can cause life-threatening problems. Explain this apparent contradiction. K/U A
5. What factors do you think are, or should be, taken into account when deciding on the most appropriate candidate to receive a lung transplant? Explain your reasoning. K/U T/I A
6. (a) There are protocols in place for individuals who wish to donate their organs after their death. Use the Internet and other sources to research the organ donation programs and policies in Ontario. Write a brief summary of your findings.
   (b) Have you made a personal decision regarding organ donation? Discuss your feelings on this issue with a classmate. Record your arguments for and against organ donation. T/I C A

GO TO NELSON SCIENCE

10.6 Explore an Issue in Healthcare

Is Healthcare a Right, a Privilege, or a Responsibility?

SKILLS MENU

- Defining the Issue
- Researching
- Identifying Alternatives
- Analyzing
- Defending a Decision
- Communicating
- Evaluating

Research has clearly established the link between smoking and respiratory diseases such as asthma, emphysema, and lung cancer. Smoking is known to cause other diseases, such as coronary artery disease, stroke, and cancer. Smoking, and second-hand smoke, have a negative effect on most organs in the body and are detrimental to good health.

The leading causes of smoking-related deaths are lung cancer, cardiovascular disease, and airway obstruction. It is estimated that smoking is responsible for 90 % of all lung cancers in men, 80 % of all lung cancers in women, and 90 % of deaths from COPD. Approximately 45 000 premature smoking-related deaths occur in Canada each year. A lifelong smoker has an average life expectancy that is 15 years less than that of a non-smoker.

In addition to the health and social impacts, the economic costs of smoking are significant. Economic costs include the cost of cigarettes, lost productivity in the workplace, long-term disability, direct healthcare costs, and premature death. While estimates vary considerably, there is little doubt that the costs associated with smoking are staggering. The direct cost of preventable smoking-related diseases to the Ontario healthcare system is about $1.6 billion annually, with an additional $4.4 billion in lost productivity. Taxes on tobacco generate about $1.4 billion in revenue for the government.

The Issue

Individuals assume the largest share of responsibility for their own health. We are responsible for following a healthy lifestyle, getting regular medical checkups, following our doctor's advice, and using the healthcare system only when necessary. Since smoking is not a part of a healthy lifestyle, smokers have not taken responsibility for their health. Many people consider smoking-related illnesses self-inflicted and feel they should not be expected to accept the burden of any social or economic costs.

Some jurisdictions have discussed the idea of withholding certain medical treatments for patients who smoke. While this is not being actively considered in Canada, it is indirectly taken into account in certain situations. For example, an individual who continues to smoke through conventional treatment for emphysema is unlikely to be considered as a candidate for a lung transplant.

The healthcare system is funded by money from taxpayers. The issue is whether or not the healthcare system should be allowed to withhold medical treatment from individuals with smoking-related diseases if they continue to smoke. Is healthcare a right, a privilege, or a responsibility?

Health Canada has asked an advisory committee to help determine whether there should be restrictions on the availability of treatments or therapies for smokers who develop smoking-related diseases. The committee has been established by Health Canada and will report to the Parliament of Canada. The committee members include

- a citizen/patient (smoker)
- a family physician
- an oncologist (cancer specialist)
- a Ministry of Health representative
- a tobacco industry representative
- a Canadian Medical Association representative
- a medical ethicist
- a psychologist (addiction specialist)
- a citizen/patient (non-smoker)
- a pulmonologist (lung disease specialist)
- a healthcare administrator
- an economist
- a lawyer
- a social ethicist

Goal

To gather input from all stakeholders and prepare recommendations to the Parliament of Canada regarding the right of the healthcare system to withhold certain medical treatments or therapies from smokers with smoking-related diseases, and the responsibility for the cost of such treatments or therapies

Research

SKILLS HANDBOOK A2.1, A5.1

For this activity, you will work in a group of 5 to 6 people. Each person in your group will represent a committee member. Select one of the given roles or that of a stakeholder not listed above. Think about your role. What relevant background do you have? How are you affected by the issue? Research the issue and gather information to support the viewpoint of the role you have chosen. Consider the following points to help guide your research:

- the experience of other jurisdictions where this issue has been explored
- the legal and ethical considerations of the issue
- the medical evidence concerning the success or lack of success of treatments
- the economic cost related to smoking-related illnesses and deaths
- the average age when people start smoking and become addicted

WEB LINK

To begin your research on this topic,

GO TO NELSON SCIENCE

Identify Solutions

SKILLS HANDBOOK A2.1, A5.2

There are several possible decisions that can be reached on this issue. Below are three possible decisions, but you are encouraged to consider others.

- Lifestyle behaviours, such as smoking, should not be considered when deciding on medical treatments and therapies. No citizen should be denied available treatment or therapy for a smoking-related medical condition.
- Lifestyle behaviours, such as smoking, should be a significant factor in deciding on medical treatments and therapies for smoking related illnesses. The healthcare system should have the authority to withhold treatment if the patient does not comply with the advice of the medical team.
- Medical treatments and therapies should be available to everyone, regardless of their lifestyle behaviours. However, the cost of these treatments and therapies for smoking-related illnesses should be shared by the patient.

LEARNING TIP

Reaching a Consensus

Reaching a consensus in a group requires coming to an agreement, but it does not necessarily mean reaching a unanimous decision. However, the decision should be representative of the group and should reflect the following considerations:

- The group should represent as many stakeholders as possible.
- The goal of the group is to reach a common solution, even though there are differences of opinion.
- Each member's input is weighted the same.
- Members must be willing to compromise so that the decision of the group is acceptable to everyone, rather than just the majority.

Make a Decision

While individual members assume a personal or professional position on the issue, the committee should attempt to reach a consensus decision.

Communicate

Your committee will prepare a report containing the appropriate background information, a set of recommendations, and the rationale for the recommendations. The report should represent the consensus of the committee. The report may be presented in any appropriate print or digital format.

Plan for Action

As people age, they generally require more services from the healthcare system. As the average age of the population increases, so does the cost of universal healthcare. Can universal healthcare survive in its current form, or will changes be required in the years ahead?

- Contact your provincial Ministry of Health and Health Canada to determine what plans have been made to deal with the rising cost of healthcare.
- With a classmate, brainstorm ideas that might help control the cost of publicly funded healthcare. Write a letter to your MP and your MPP outlining your suggestions.
- Make a personal plan to avoid placing an excessive strain on the healthcare system.

GO TO NELSON SCIENCE

CHAPTER 10 Investigations

Investigation 10.2.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Determining Lung Volume and Oxygen Consumption

Lung volume varies among individuals and depends on many factors, such as sex, body size, physical fitness, and lifestyle behaviours such as smoking. One indicator of physical fitness is the maximum amount of oxygen that the body uses during strenuous activity. You can use an instrument called a spirometer to measure the amount of air that you breathe during normal breathing or during forced inhalation and exhalation. The breathing rates before and during strenuous activity can then be used to determine the maximum amount of oxygen used by an individual.

Purpose

In Part A of this activity, you will measure your lung capacity at rest. In Part B, you will calculate the rate at which oxygen is used in your body (VO_2), and in Part C, you will determine the maximum amount of oxygen that your body can use during sustained, intense physical activity (VO_2max).

Equipment and Materials

- spirometer
- disposable mouthpiece
- stopwatch
- bathroom scale
- measured race track or GPS

The spirometer is designed to measure the volume of air that is forced into it. Do not inhale through the mouthpiece of the spirometer at any time.

Procedure

SKILLS HANDBOOK A1.2, A2.4, A6.2

Part A: Determining Lung Volume

1. Prepare a table similar to **Table 1** in which to record your data.
2. Set the gauge on the spirometer to zero and, if necessary, empty the entire spirometer chamber. Attach a new, unused mouthpiece.
3. Breathe normally for a few breaths to establish a regular breathing pattern. After a normal inhalation, place the mouthpiece in your mouth and exhale normally. Record the volume of air exhaled. This is your tidal volume (TV). Repeat this twice, resetting the spirometer each time, for a total of three measurements. Calculate the average volume of air exhaled and record it as the average tidal volume (TV) in your table.

Table 1 Lung Capacity Data

	Volume (L)			
	Trial 1	Trial 2	Trial 3	Average value
tidal volume (TV)				
forced exhalation volume (FEV)				
vital capacity (VC)				

4. Reset the gauge to zero and, if necessary, empty the entire spirometer chamber. Inhale normally and place the mouthpiece in your mouth. Exhale forcibly and record the volume of air exhaled. This is your forced exhalation volume (FEV). Repeat this twice, resetting the gauge each time, for a total of three measurements. Calculate the average volume of air exhaled and record it as the average forced exhalation volume (FEV).
5. Reset the gauge to zero and, if necessary, empty the entire spirometer chamber. Inhale as deeply as possible, and place the mouthpiece in your mouth. Exhale as much air as possible. Record the volume of air exhaled. This is your vital capacity (VC). Repeat this twice, resetting the gauge each time, for a total of three measurements. Calculate the average volume of air exhaled and record it as the average vital capacity (VC).

Part B: Determining VO_2

To determine your VO_2, you need the following information:

- Oxygen constitutes 20.9 % of atmospheric air.
- Only 20 % of the available oxygen in the air is absorbed in your lungs.
- VO_2 is the at-rest rate of oxygen consumption per kilogram of body mass per minute. The unit used to express VO_2 is mL/kg/min.

6. To determine your ventilation rate, use a stopwatch to time 1 min and count the number of breaths you take in 1 min. Try to breathe normally.
7. Use a scale to determine your mass in kilograms.
8. Use the following formula to determine your VO_2:

   VO_2 = (ventilation rate × tidal volume × 20.9 % × 20 %) ÷ mass

   Record your VO_2.

Part C: Determining VO_2max

The Cooper 12-Minute-Run Test is an indirect method to estimate VO_2max. In this test, the individual walks and/or runs as fast as he or she can for 12 min. Results are based on the distance covered in that time. This is an individual test, not a race. There is no competition, but you are expected to try your best.

This is a strenuous activity. Inform your teacher if there is any medical reason why you should not participate in this test.

9. Warm up for 10 min prior to walking or running.
10. On a track or level area, walk or run as fast as you can for 12 min. Determine the distance covered to the nearest 0.01 km.
11. Use the following formula to estimate your VO_2max. This method yields values with the same units as the VO_2 calculation above.

    VO_2max = (22.351 × distance covered in km) − 11.288

    Record your VO_2max.

Analyze and Evaluate

(a) Use the following formula to determine your expiratory reserve volume (ERV): T/I

ERV = FEV − TV

(b) Use the following formula to determine your inspiratory reserve volume (IRV): T/I

VC = IRV + ERV + TV

(c) Why do you think it is important to take the average of three measurements instead of taking only one measurement each for your tidal volume, forced exhalation volume, and vital capacity? T/I

(d) What additional information would you need to determine your total lung capacity (TLC)? Write two different formulas for determining the TLC. (Hint: Refer back to Figure 6 on page 443.) T/I C

(e) Explain the significance of each component of the equation used to calculate VO_2. T/I A

(f) Refer to Table 1 on page 444 to determine your VO_2max efficiency level. T/I

(g) What are possible disadvantages of using an indirect method of determining VO_2max? T/I

(h) Identify possible sources of error in the procedure used to determine VO_2 and VO_2max. How can these be reduced or eliminated? T/I

Apply and Extend

(i) People with emphysema often feel as if they cannot exhale properly. How would the lung volumes of a person with emphysema compare with those of an average healthy person? How might the values in the VO_2 equation need to be adjusted? What part of the VO_2 equation might be altered? T/I A

(j) Predict how the vital capacity of an Olympic athlete would compare with the vital capacity of an average person. How would the VO_2max of these two individuals compare? A

(k) Would an increase in altitude affect an individual's VO_2 or VO_2max? Explain your answer. T/I A

(l) Use the Internet and other sources to find information about how VO_2max is used. Present your findings in a brief written or oral report. T/I C A

GO TO NELSON SCIENCE

Investigation 10.2.2 CORRELATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

The Relationship between Long-Term Exercise and Vital Capacity

Vital capacity is a function of lung volume. Therefore, vital capacity varies depending on the same factors that affect lung volume, such as age, sex, body size, genetics, and lifestyle choices. The lifestyle choice you will focus on in this investigation is an individual's level of regular physical activity.

Purpose

In this activity you will analyze data to investigate the relationship between lifestyle and vital capacity.

Variables

SKILLS HANDBOOK A2.1

The two main variables in this investigation are lifestyle and vital capacity. Lifestyle is defined in terms of the level of physical activity that an individual engages in on an ongoing basis. Individuals are rated on a five-point scale, as follows:

1. inactive, no exercise on a regular basis
2. somewhat active, exercise once a week
3. moderately active, exercise three times a week
4. very active, exercise five or more times a week
5. extremely active, exercise every day

The vital capacity is defined as the maximum working volume of the lungs. Vital capacity depends on many variables, such as sex, age, height, and mass.

Study Design

SKILLS HANDBOOK A2.3

A random sample was selected from the school population. Data were collected regarding their sex and physical activity rating. Vital capacity was measured using a spirometer. Your teacher will provide the raw data for you.

You will use appropriate software to determine the correlation between the two variables.

Equipment and Materials

- raw data
- computer with a spreadsheet program

Procedure

SKILLS HANDBOOK A1.2, A2.3

1. Obtain the raw data from your teacher.
2. Select the data for your study group. If necessary, create a new table and record your selected data. Remember that lung capacity varies depending on several variables, so you may want to restrict your study to only males or only females.
3. Enter the selected data into the appropriate software and determine the correlation coefficient between the two variables.

Analyze and Evaluate

SKILLS HANDBOOK A2.3

(a) What variables were observed or measured in this study? Which variables, if any, did you control by your selection of data? What type of relationship is being tested? T/I

(b) What does the value of the correlation coefficient indicate about the relationship between the two variables? T/I

(c) Why is this study designed as a correlational study rather than a controlled experiment? What is the benefit of conducting a correlational study in this case? T/I

(d) Based on the data from this study, can you conclude that regular exercise causes an increase in vital capacity? Why or why not? T/I

Apply and Extend

(e) Propose a hypothesis that might explain the relationship between the variables in this study. T/I

(f) Design a controlled experiment that could be conducted to test this hypothesis. T/I A

(g) What would be the advantage of a controlled experiment over a correlational study? T/I A

(h) Do you think singers or musicians who play wind instruments would have a larger vital capacity than individuals who do not participate in those activities? Explain your answer. C A

(i) Predict the relationship between sex and vital capacity. Use the available data to check your prediction. A

CHAPTER 10 SUMMARY

Summary Questions

1. Create a study guide based on the Key Concepts listed at the beginning of the chapter, on page 436. For each point, create three or four subpoints that provide further information, relevant examples, explanatory diagrams, or general equations.
2. Return to the Starting Points questions at the beginning of the chapter, on page 436. Answer these questions using what you have learned in this chapter. Compare your answers with those that you gave at the beginning of the chapter. How has your understanding changed? What new knowledge and skills do you have?

Vocabulary

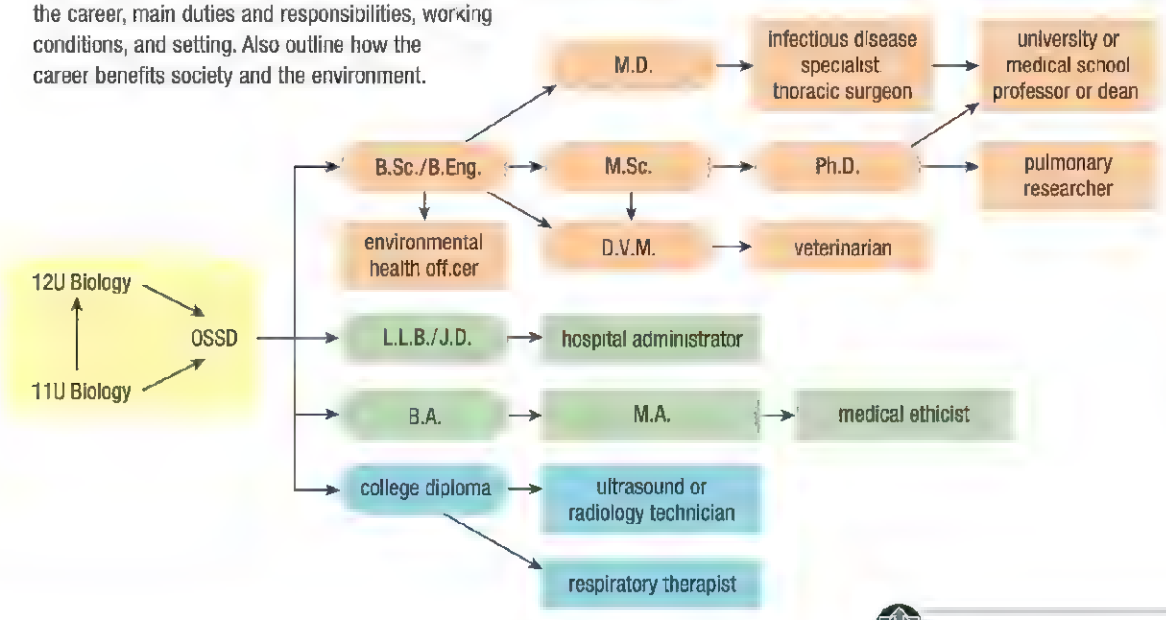
aerobic cellular respiration (p. 438)
phosphorylation (p. 438)
gas exchange (p. 438)
ventilation (p. 439)
trachea (p. 441)
bronchus (p. 441)
bronchiole (p. 441)
alveolus (p. 441)
diaphragm (p. 442)
external intercostal muscle (p. 442)
internal intercostal muscle (p. 442)
pleural membrane (p. 443)
pneumothorax (p. 443)
total lung capacity (p. 443)
tidal volume (p. 443)
inspiratory reserve volume (p. 443)
expiratory reserve volume (p. 443)
residual volume (p. 443)
vital capacity (p. 443)
VO_2 (p. 444)
VO_2max (p. 444)
partial pressure (p. 447)
plasma (p. 448)
hemoglobin (p. 448)
asthma (p. 452)
chronic obstructive pulmonary disease (COPD) (p. 453)
tuberculosis (TB) (p. 454)
pneumonia (p. 455)
FLAP inhibitors (p. 459)
bronchial thermoplasty (p. 459)
lung transplant (p. 461)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or postgraduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select two careers related to the respiratory system that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



GO TO NELSON SCIENCE

CHAPTER 10 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which of the following best describes the purpose of aerobic cellular respiration? (10.1) K/U
   (a) to provide oxygen for the body cells
   (b) to provide oxygen for the lungs
   (c) to break down ATP into ADP
   (d) to provide energy for the body
2. How is the majority of the energy that is released in aerobic cellular respiration used? (10.1) K/U
   (a) It is stored as ADP.
   (b) It is stored as ATP.
   (c) It is released as heat.
   (d) It is stored as heat.
3. Where does gas exchange take place in the human body? (10.1) K/U
   (a) in the lungs only
   (b) in the lungs and body cells
   (c) in the body cells only
   (d) in the lungs and skin
4. Which of the following best describes the process of ventilation? (10.2) K/U
   (a) Oxygen moves into the lungs.
   (b) Carbon dioxide moves out of the lungs.
   (c) Oxygen moves into the lungs and carbon dioxide moves out.
   (d) Oxygen moves into the body cells and carbon dioxide moves out.
5. Which respiratory structure sequence is correct? (10.2) K/U
   (a) trachea, bronchi, bronchioles, alveoli
   (b) trachea, bronchioles, bronchi, alveoli
   (c) trachea, alveoli, bronchi, bronchioles
   (d) trachea, alveoli, bronchioles, bronchi
6. During inhalation, the diaphragm contracts, causing
   (a) the volume of the lungs to decrease
   (b) the volume of the lungs to increase
   (c) air to be forced out of the lungs
   (d) oxygen to diffuse across lung membranes (10.2) K/U
7. In the lungs, most of the oxygen taken in diffuses into the blood and
   (a) binds to hemoglobin
   (b) gets dissolved by hemoglobin
   (c) dissolves in blood plasma
   (d) binds to blood plasma (10.3) K/U
8. Chronic obstructive pulmonary disease (COPD) is a combination of which diseases? (10.4) K/U
   (a) asthma and bronchitis
   (b) emphysema and bronchitis
   (c) emphysema and pneumonia
   (d) cystic fibrosis and tuberculosis
9. Immunosuppressive drugs given to transplant patients
   (a) make the patients more susceptible to infections
   (b) prevent the immune system from rejecting the transplanted organ
   (c) must be taken for the rest of the patient's life
   (d) all of the above (10.5) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

10. The energy stored in ATP is used by cells to power almost all energy requiring processes. (10.1) K/U
11. In countercurrent exchange, blood low in oxygen flows in the opposite direction to water high in oxygen. (10.2) K/U
12. Gases will diffuse across a membrane from an area of lower pressure to an area of higher pressure. (10.3) K/U
13. High-altitude training increases erythropoietin (EPO) in the blood, which carries oxygen. (10.3) K/U
14. An increase in blood acidity will cause you to breathe more slowly. (10.3) K/U
15. Emphysema causes breathing difficulties by causing pus and mucus to build up in the alveoli. (10.4) K/U
16. Bacterial pneumonia can be successfully treated with antibiotics. (10.4) K/U
17. Having just a single allele for cystic fibrosis can cause a person to suffer from symptoms of the disease. (10.4) K/U
18. FLAP inhibitors bind to FLAP proteins and cause inflammatory chemical production to increase. (10.5) K/U
19. The greatest problem faced by patients needing lung transplants is infection. (10.5) K/U

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CHAPTER 10 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. Cells cannot carry out basic life functions without having a continuous supply of which gas? (10.1) K/U
   (a) oxygen
   (b) nitrogen
   (c) carbon dioxide
   (d) water vapour
2. What is the primary purpose of aerobic cellular respiration? (10.1) K/U
   (a) to provide oxygen for cells
   (b) to provide food for cells
   (c) to break down oxygen
   (d) to provide energy for cells
3. In aerobic cellular respiration, what happens during phosphorylation? (10.1) K/U
   (a) ATP is turned into ADP.
   (b) ADP is turned into ATP.
   (c) ADP loses a phosphate group to form ATP.
   (d) ATP gains a phosphate group to form ADP.
4. Which two terms are synonymous? (10.1) K/U
   (a) ventilation and breathing
   (b) ventilation and gas exchange
   (c) gas exchange and breathing
   (d) gas exchange and aerobic cellular respiration
5. Which feature is required for a terrestrial mammal's respiratory system? (10.2) K/U
   (a) thin permeable membrane with large surface area
   (b) breathing system for bringing air in and out
   (c) good supply of blood
   (d) all of the above
6. Which of the following carries most of the oxygen to the body cells? (10.3) K/U
   (a) blood plasma
   (b) hemoglobin
   (c) white blood cells
   (d) platelets
7. An increase of carbon dioxide in the blood will stimulate which of the following to occur? (10.3) K/U
   (a) heart rate to decrease
   (b) breathing rate to double
   (c) both heart rate and breathing rate to increase
   (d) both heart rate and breathing rate to decrease
8. Which of the following diseases is characterized by chronic inflammation of bronchi and bronchioles? (10.4) K/U
   (a) pneumonia
   (b) cystic fibrosis
   (c) influenza
   (d) asthma

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

9. All organisms have either lungs or gills that they use for gas exchange. (10.1) K/U
10. Oxygen makes up about 20.9 % of the air that we breathe. (10.3) K/U
11. When carbon dioxide diffuses into the bloodstream from body cells, it reacts with water molecules and forms carbonic acid, which lowers the pH of the blood. (10.3) K/U
12. Asthma appears to be caused by the body's protective response to foreign materials that enter the respiratory system. (10.4) K/U
13. Antibiotics are effective in treating both viral and bacterial infections. (10.4) K/U
14. A person with one defective allele for the gene that causes cystic fibrosis will show mild symptoms of the disease, while a person with two alleles will show all the symptoms of the disease. (10.4) K/U

Match each term on the left with the most appropriate description on the right.

15.

(a) alveoli	(i) passages to lungs
(b) epiglottis	(ii) site of gas exchange
(c) bronchi	(iii) the smallest branches of the respiratory tree
(d) bronchioles	(iv) keeps food out of trachea (10.2) K/U

16.

(a) expiratory reserve volume	(i) maximum volume of air that can be exhaled in a single breath
(b) total lung capacity	(ii) air volume that remains in lungs after exhaling
(c) vital capacity	(iii) maximum air volume that can be inhaled or exhaled
(d) residual volume	(iv) volume of air that can be forcibly exhaled after a normal exhalation (10.2) K/U

Write a short answer to each question.

17. Describe the flow of blood and oxygen-rich water in the gills of an aquatic animal. Explain how this maximizes the differences in oxygen concentration. (10 2) K/U

18. **Figure 1** shows a diagram of the human respiratory system. In your notebook, match the following labels to the appropriate letter in Figure 1: lung, bronchioles, bronchi, larynx, pharynx, diaphragm, epiglottis, external intercostal muscles. (10.2) K/U

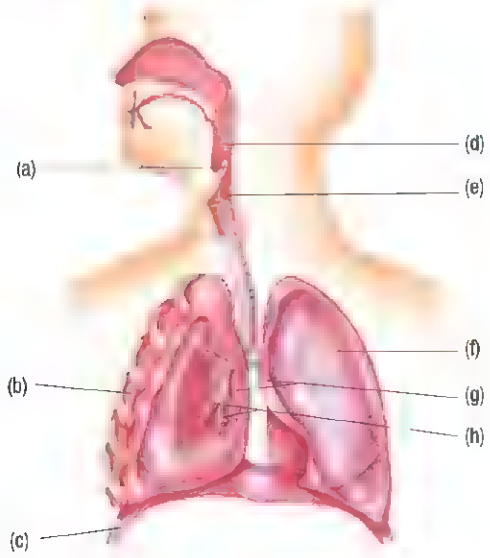

Figure 1 The human respiratory system

19. A pop bottle with a carbon dioxide partial pressure of 0.6 kPa and an oxygen partial pressure of 22.0 kPa is opened in an environment with a carbon dioxide partial pressure of 0.0397 kPa and an oxygen partial pressure of 21.17 kPa. Which gas(es) will diffuse into the environment? (10.3) K/U T/I

20. At an elevation of 7000 m, atmospheric pressure is 40 kPa. What is the partial pressure of oxygen at this altitude if oxygen makes up 20.9 % of the atmosphere? (10.3) T/I

21. The partial pressure of oxygen in capillary A is 5.33 kPa. The partial pressure of oxygen in capillary B is 13.33 kPa. (10.3) K/U T/I
    (a) Which capillary, A or B, is approaching the lungs?
    (b) Which capillary is approaching body tissues?

22. What component in blood counteracts the dangerous accumulation of hydrogen ions in the blood and tissue fluid? (10.3) K/U

23. What is detected by the chemical receptors in the brain that causes an increased breathing rate and heart rate? (10.4) K/U

Understanding

24. In aerobic cellular respiration, what is the ratio of ATP molecules created for every molecule of glucose that undergoes cellular respiration? (10.1) K/U

25. What is the process in aerobic cellular respiration that is responsible for forming ATP from ADP called? (10.1) K/U

26. What are the two locations in which gas exchange takes place in the human body? (10.2) K/U

27. In gas exchange, why must all diffusion of oxygen and carbon dioxide occur across a moist membrane? (10.2) K/U T/I

28. Copy and complete **Table 1**. Describe the changes that occur in each structure during the inhalation and exhalation stages of breathing. (10.2) K/U

Table 1 Stages of Ventilation

	Inhalation	Exhalation
diaphragm		
intercostal muscles		
lungs		
thoracic cavity		

29. An athlete trains at an altitude of 2000 m for several weeks. (10.3) K/U
    (a) The secretion of which substance is likely to increase in the athlete's blood?
    (b) What will be the effect of the increase of this substance?
    (c) How will the change in the athlete's blood composition change his performance?

30. (a) What function do the stretch receptors in the lungs serve?
    (b) What might happen if the stretch receptors were damaged? (10.3) K/U T/I

31. A patient comes to a clinic and is found to have a shortage of red blood cells in his blood. (10.3) K/U T/I
    (a) Explain how a shortage of red blood cells would affect the amount of hemoglobin in the patient's blood.
    (b) Explain how a shortage of red blood cells would affect the concentration of oxygen in the patient's blood.
    (c) Explain how a shortage of red blood cells would affect the pH of the patient's blood.

32. Samples of a runner's blood are taken continuously during an extended run on a treadmill. Measurements of oxygen level, breathing rate, heart rate, and carbon dioxide level are taken. (10.3) K/U T/I
    (a) Which substance would you expect to build up in the blood as time passes?
    (b) Which substance would you expect to decrease in the blood as time passes?
    (c) How would you expect the heart rate and breathing rate to change as a result of these changes in blood composition?
    (d) How would you expect the pH of the blood to change as time passes? Why does it change?
    (e) Where is this pH change detected in the body?
    (f) How is the pH change counteracted in the body?
33. What is the stimulus that causes hemoglobin to release its bound oxygen into blood plasma so that the oxygen can diffuse into cells? (10.3) K/U
34. After oxygen enters cells it combines with glucose to produce carbon dioxide, water, and the release of energy. As metabolism continues, carbon dioxide builds up in the cell and diffuses into the blood. In what three ways is this carbon dioxide transported through the blood? (10.3) K/U T/I
35. A chemist points out that if you dissolve carbon dioxide in water, it forms carbonic acid. She notes that this formation of acid could pose a danger by causing blood carrying carbon dioxide to become too acidic. What prevents this from occurring? (10.3) K/U T/I
36. A doctor suspects that her patient has either asthma or COPD. The doctor uses **Table 2** to evaluate the patient. Copy the table and write asthma, COPD, or both asthma and COPD for each category. (10.4) K/U T/I C

Table 2 Respiratory System Ailments

(a) more serious condition	
(b) symptoms of coughing, wheezing, and shortness of breath	
(c) typically caused by cigarette smoking	
(d) involves inflammation	
(e) involves damage to alveoli	
(f) responds well to dilation of bronchi	
(g) likely to cause heart failure or pneumonia	

37. A 10-year-old girl in a clinic has been diagnosed with asthma. (10.4) K/U T/I
    (a) What are some possible environmental stimuli of asthma? How does the body respond to these stimuli?
    (b) In what part of the body are the effects of asthma seen?
    (c) What symptoms result from the body's response to the environmental stimuli?
    (d) What kinds of medications can relieve the symptoms of asthma?
38. Suppose you suspected that you had contracted a strain of influenza. (10.4) K/U T/I
    (a) What symptoms would you expect to have?
    (b) If you do have the flu, what kinds of treatments would you seek out?
    (c) How successful would you expect treatment of the flu to be?
    (d) What consequences would you suffer if you failed to get treatment?
    (e) How contagious would your infection likely be?
    (f) What could you do to prevent spreading your illness to others?
39. Compare the major ailments of the respiratory system, including influenza, pneumonia, COPD, tuberculosis, cystic fibrosis, and lung cancer. Copy and complete **Table 3**. (10.4) K/U T/I C

Table 3 Respiratory System Ailments

Ailment	Usually caused by	Best treated with	Success of treatment
influenza			
pneumonia			
COPD			
tuberculosis			
cystic fibrosis			
lung cancer			

40. A scientist has developed a promising new FLAP inhibitor drug. She now wants to test the drug with a variety of patients. (10.5) K/U T/I
    (a) What kind of diseases would patients in this study be likely to have?
    (b) How does a FLAP inhibitor work?
    (c) Explain why the drug might also prove effective in treating diseases that do not involve the respiratory system.

Analysis and Application

41. The blood of a diabetic patient contains plenty of oxygen and sugars (glucose). However, without the special hormone insulin, the patient's cells are unable to transport sugars across cell membranes. Describe a symptom that you would expect a diabetic patient to develop as a result of this situation. Explain the symptom in terms of the basic equation for aerobic cellular respiration. (10.1) K/U T/I A

42. Compare and contrast ventilation and gas exchange. (10.1) K/U T/I
    (a) Where does each process take place?
    (b) Can you have ventilation without gas exchange? How would it occur? What would be the consequences of ventilation without gas exchange?
    (c) Can you have gas exchange without ventilation? How would it occur? What would be the consequences of gas exchange without ventilation?

43. Plants carry out photosynthesis by taking in water and carbon dioxide to create energy-rich glucose molecules, releasing oxygen in the process. What is the relationship between the basic process of photosynthesis and the process of aerobic cellular respiration? How are the products of photosynthesis related to the reactants of aerobic cellular respiration? (10.1) K/U T/I A

44. In the process of aerobic cellular respiration, what is the advantage of using energy to produce ATP from ADP? Why do cells not simply convert all of the energy into heat or some other form of energy that is immediately available for use? (10.1) K/U T/I

45. Can an animal that has neither lungs nor gills still carry out gas exchange and aerobic cellular respiration? Use an example to explain your answer. (10.1) K/U A

46. The lungs of humans and almost all other land animals are located deep inside the body. Gills, on the other hand, are typically located on the outside of the body on fish. Explain why lungs are almost always interior organs and gills are exterior organs. (10.2) K/U T/I

47. A scientist is looking for a way to determine the residual volume of a patient's lungs. The scientist is able to measure the patient's total lung capacity and his vital capacity. How can she find the residual volume? (10.2) K/U T/I

48. As a result of training, Sarah increased her VO_2max by 20 %. What is the result of this gain? Explain your answers. Will Sarah
    (a) take in more oxygen than she did before?
    (b) burn more glucose than she did before?
    (c) produce more ATP than she did before? (10.2) T/I A

49. A student points out that at sea level, the partial pressure of oxygen is 21.17 kPa while the partial pressure for carbon dioxide is only 0.0397 kPa. He claims that this means oxygen will diffuse across a membrane much faster than carbon dioxide. What is wrong with the student's thinking? Explain. (10.3) K/U T/I A

50. An astronaut on the planet Venus opens an ordinary pop bottle that is bottled under pressure, and nothing happens—no bubbles escape from the liquid. What does this tell you about the atmosphere of Venus? (10.3) T/I A

51. Insect blood carries nutrients to cells, just like the blood of mammals does. Insect blood has a greenish or yellow colour. What does the colour tell you about the composition of insect blood? (10.3) T/I A

52. A patient comes to a clinic complaining of shortness of breath. Her heart and lungs are both shown to be functioning normally. A medical student correctly determines that the patient is suffering from low blood oxygen. The student suggests that the patient be given extra blood plasma. (10.3) K/U T/I A
    (a) Why was the student's suggestion to administer extra blood plasma a mistake?
    (b) What can be added to the patient's blood that might be more helpful?
    (c) Why will the addition of this substance be likely to help the patient?

53. You are riding your bike up a steep hill, burning oxygen and sugar at a high rate. Your heart and breathing rates quickly increase to keep up with the increased demand of oxygen and sugar that your muscles need to keep working at a high rate. (10.3) K/U T/I A
    (a) What stimulus signals your heart and breathing rates to increase?
    (b) Describe the sequence of events that controls this heart and breathing rate increase.

54. Inflammation consists of increased blood flow that causes swelling and the production of mucus. Inflammation that causes asthma is said to be a protective reaction of the body to combat foreign substances. Describe a scenario in which this inflammatory response would be considered beneficial to the body. (10.4) K/U T/I A

55 A woman and her husband both carry a single allele for the defective version of the gene responsible for cystic fibrosis (CF). (10.4) K/U T/I
   (a) What is the likelihood that either spouse will develop CF in his or her lifetime? Explain.
   (b) What is the likelihood that a child of this couple will develop CF? Explain.

56. There is no effective cure for emphysema, one of the two diseases that make up COPD. Why is this disease so hard to treat? (10.4) K/U T/I

57. Infection with HIV (human immunodeficiency virus) leads to the failure of the immune system. During the rise of HIV infections in the late 1980s and 1990s, tuberculosis re-emerged as a serious health threat. Why do you think this occurred? (10.4) T/I A

58. Smoking has been banned in many places throughout North America and the rest of the world. (10.4) K/U A
   (a) Which diseases has smoking been proven to be a cause of or contributor to?
   (b) Which chemicals in cigarette smoke have been shown to cause disease or be harmful in some way? Explain the effect of these chemicals.
   (c) Of the harmful chemicals in cigarette smoke, which chemical do you consider the most harmful? Explain your choice.

59. Carbon monoxide is the chemical in automobile exhaust that can prove fatal for people who run their cars in a closed garage without ventilation. (10.4) K/U T/I A
   (a) Explain how carbon monoxide interferes with gas exchange.
   (b) Explain why carbon monoxide in cigarette smoke is not immediately deadly the way it is in car exhaust.
   (c) Describe the symptoms that would be likely to result from breathing in large quantities of carbon monoxide.

Evaluation

60. A soccer coach has arranged for her players to have their VO_2max measured. (10.2) K/U T/I A
   (a) What ability does VO_2max measure? What units does VO_2max use to make these measurements?
   (b) How can measuring VO_2max help the coach evaluate her players?
   (c) How is a player with a high VO_2max measurement likely to be different from a player with a low VO_2max measurement?
   (d) How does a VO_2max measurement reflect how healthy a player's lungs are?
   (e) How is a VO_2max measurement an indication of a player's muscles as well as her lungs?

61. Suppose a scientific funding committee received three funding proposals from research scientists. The first proposal would work on removing the carcinogenic components from cigarette smoke. The second proposal would work to eliminate the destructive components from smoke that irritate airway linings, destroy cilia, and clog alveoli. The third proposal would work to eliminate the addictive properties of cigarette smoke and nicotine. Assume that all three proposals are equally likely to succeed. (10.4) T/I A
   (a) Speculate about the potential strengths and weaknesses of the first proposal to remove carcinogenic compounds from cigarette smoke.
   (b) Speculate about the potential strengths and weaknesses of the second proposal.
   (c) Speculate about the potential strengths and weaknesses of the third proposal.
   (d) In your view, which project would likely save the greatest number of lives? Which would save the fewest number of lives?
   (e) Which proposal would you recommend that your committee adopt? Rank your choices from 1 to 3. Explain your choices.

62. Tuberculosis (TB) was once one of the most deadly diseases on Earth. Then, in the middle of the twentieth century, TB suddenly became much less of a threat. (10.4) K/U T/I A
   (a) What made TB such a serious disease to begin with?
   (b) What happened in 1948 to reduce the threat that TB posed?
   (c) Why did people think that TB would disappear in the years following 1948?
   (d) What factors have contributed to the continuing threat of TB in recent years?
   (e) Is TB likely to be eliminated in the future? Give reasons to support your answer.

63. Suppose you were assigned by the United Nations to lead a campaign to eliminate TB. (10.4) T/I A
   (a) What kind of medical research programs would you focus on?
   (b) What kind of public health programs would you focus on?
   (c) Would you get governments involved in your efforts? If so, how could governments help eliminate TB?

64. Lung transplants help some people survive, but they are also expensive, difficult, and require a great deal of resources. Should the number of lung transplants be increased in the future? State your position on this issue. (10.5) T/I A

Reflect on Your Learning

65. Reflect on your observation of fish as they swim in water. When you look at the gills of fish, why do they appear to be moving? What do you think this movement accomplishes? T/I C A
66. How concerned are you about your future children having cystic fibrosis? Explain. K/U T/I A
67. What single thing can you do to avoid most of the diseases of the respiratory system described in this chapter? Explain your thinking. K/U T/I A
68. Suppose a close friend or family member needed a donor for a lung transplant and you were a good match. Would you consider losing part of your lung to help someone else? Describe your feelings about the issue. A
69. You have learned about a variety of diseases and afflictions that affect the respiratory system. If you were going to become a medical researcher, which of the problems listed in this chapter would you choose to tackle? Explain your choice. T/I A

Research

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70. Amphibians are unique organisms with respect to respiration, using lungs, gills, and skin to carry out gas exchange. Use the Internet and other sources to research the respiratory systems of amphibians. Prepare a presentation that focuses on amphibian respiratory systems. T/I C
71. CPR, or cardiopulmonary resuscitation, can save lives. Find out about CPR classes in your area. What do you need to get certified in CPR? Present your findings to your classmates. C A
72. Altitude sickness is a real problem for mountain climbers. Use the Internet and other sources to research how serious climbers avoid suffering from this condition. Create a pamphlet or poster that explains the causes and preventions of altitude sickness. T/I C A
73. Hemoglobin was one of the first proteins ever characterized in three-dimensional representations (**Figure 2**). Use the Internet and other sources to research how this protein was sequenced and mapped in three dimensions. Present your findings in a written report that includes diagrams. T/I C A

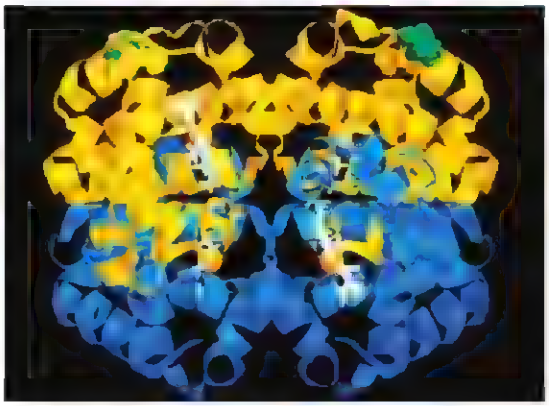


Figure 2 A hemoglobin molecule

74. FLAP inhibitors are promising drugs for fighting inflammation. Use the Internet and other sources to find out more about recent developments for these treatments. How effective are they? Which diseases and ailments do they work best for? Write a paragraph on your findings. T/I C A
75. Gene therapy has potential for combatting cystic fibrosis (CF). Use the Internet and other sources to find out how gene therapy is carried out and how it might be applied to the situation that exists for CF patients. Write a short report on your findings. T/I C A

CHAPTER 11

The Circulatory System

KEY CONCEPTS

After completing this chapter you will be able to

- explain the overall structure and functions of the circulatory system
- explain the structure and function of the main organs and tissues of the human circulatory system
- summarize the processes by which oxygen and other materials are transported to the cells of the body
- design and conduct a controlled experiment to determine how exercise affects heart rate and blood pressure
- demonstrate an understanding of common diseases and disorders and how they interfere with the main functions of the circulatory system
- evaluate technologies that are used in the diagnosis and treatment of diseases or disorders of the circulatory system
- explain the importance of lifestyle choices in maintaining a healthy circulatory system

The Beat Goes On!

Clear! The body on the gurney convulses as the doctor administers an electrical shock with a device called a defibrillator. The medical staff gather around a patient whose heart has suddenly stopped. They return to the task of trying to save his life. This is a typical scene from an emergency drama on television. Unfortunately, most heart attacks do not take place in a hospital setting. They occur most often while individuals are engaged in everyday work or recreational activities. How do we make this life saving technology available where it is needed most?

Today, you do not have to be a doctor to save someone's life in the event of a heart attack. Modern versions of the defibrillator are small, portable, relatively inexpensive, and can be used by just about anyone. They are referred to as automated external defibrillators (AEDs).

The key to saving the life of a person whose heart has suddenly stopped is a quick response. A beating heart is essential for supplying oxygen to all parts of the body. Within a few minutes of the heart stopping, the lack of oxygen in the brain will lead to brain damage and death. The first response is cardiopulmonary resuscitation (CPR) or manual compression of the chest to squeeze the heart and ensure at least minimal blood flow to the brain and other vital organs. AEDs are not intended to eliminate the need for CPR.

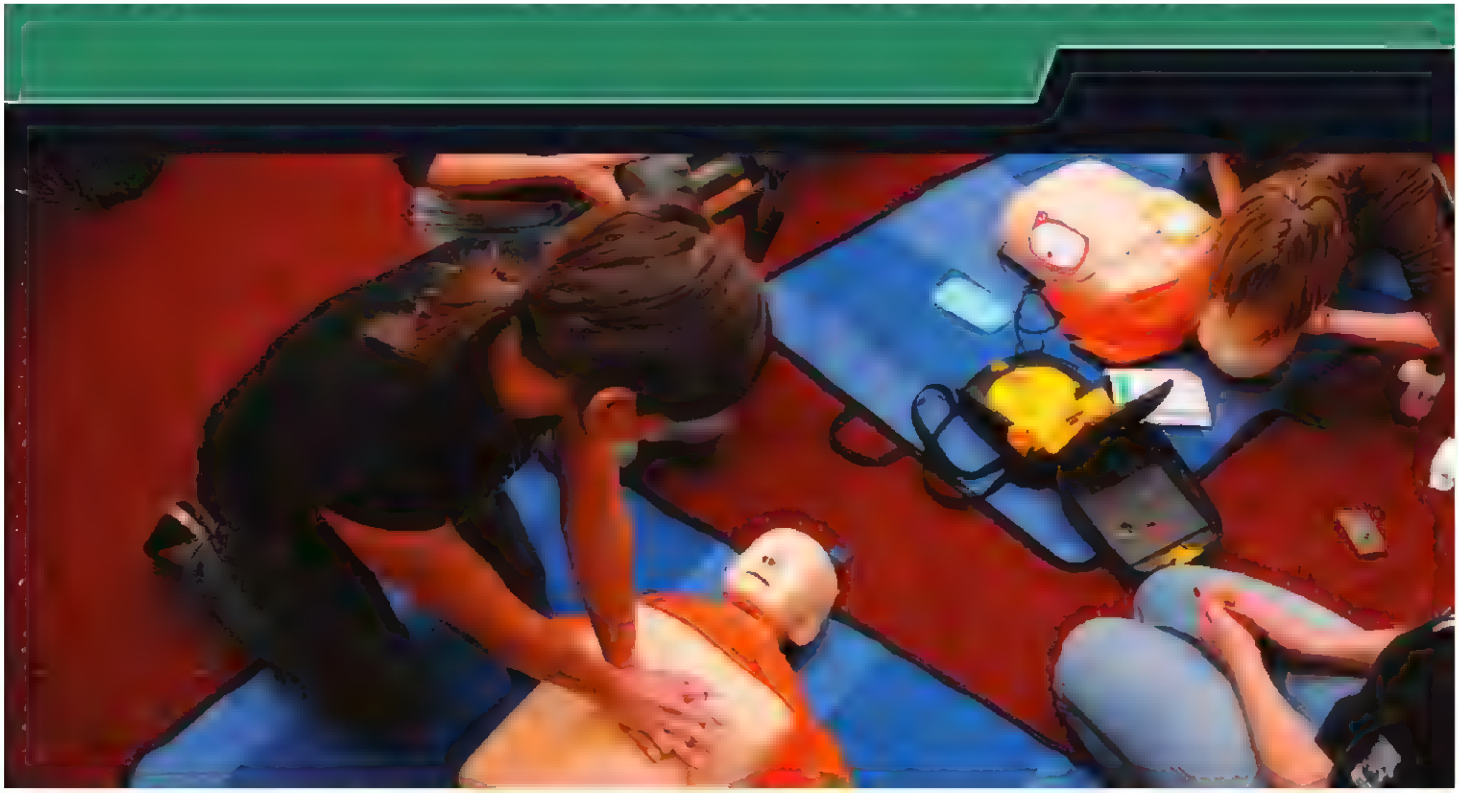
AEDs are now commonly available in public places such as schools, medical clinics, shopping malls, theatres, subway stations, health clubs, and sports arenas. With appropriate training, anyone can use an AED in an emergency situation. Many AEDs are designed to instruct the user with text and voice commands to connect the electrodes. The device will then analyze the electrical signals from the heart and determine if and when an electrical shock is necessary. If a shock is necessary, the machine warns the operator to ensure that no one is touching the patient and instructs the operator to press a button to administer the shock. Then the machine instructs the user to administer CPR. It is that simple! The chances of survival are significantly increased when CPR and defibrillation are performed within the first few minutes after a heart attack.

In this chapter you will learn about the structure and function of the heart and the circulatory system. You will also investigate some of the factors that affect the circulatory system. In addition, you will explore some of the diseases and disorders that affect the functioning of the circulatory system as well as the technologies used to diagnose and treat them.

STARTING POINTS

Answer the following questions using your current knowledge. You will have an opportunity to revisit these questions later, applying concepts and skills from the chapter.

1. List the main functions of the circulatory system.
2. Why do you think it is essential to maintain blood circulation during a medical emergency?
3. What do you think causes a heart attack? What lifestyle and other factors contribute to the likelihood of having a heart attack?
4. "It is not necessary to have automated external defibrillators (AEDs) in schools. They are only important at locations where there are mostly older people." Do you agree or disagree with this statement? Explain.
5. What signs would you look for if you thought a person was having a heart attack? What would you do if you suspected someone was having one?



Mini Investigation

Under Pressure!

Skills: Performing, Observing, Analyzing

SKILLS HANDBOOK A2.1, A3.5

In this activity, you will work with a partner and learn how to use a stethoscope and a sphygmomanometer to measure blood pressure. Remember that you are only developing a skill. You are not trying to diagnose a medical problem.

Equipment and Materials: sphygmomanometer; stethoscope

1. Ensure that your partner is seated comfortably with his or her arm resting on a desk or table.
2. Wrap the cuff of the sphygmomanometer snugly around your partner's arm just above the elbow.
3. Place the stethoscope below the edge of the cuff in the bend of the elbow (**Figure 1**).

Figure 1

4. Close the valve of the bulb. Pump air into the cuff until the gauge exceeds 200 mm Hg. (If at any time your partner feels uncomfortable, open the valve to release the pressure.)
5. Open the valve slightly and slowly release the air from the cuff. Listen for the pulse.
6. When you hear the first sounds, note the pressure on the gauge. Record the value.
7. Continue to slowly release air from the cuff. When the sound of the pulse disappears, note the pressure on the gauge again. Record the value.
8. Repeat the procedure two more times and calculate the averages of each value.
9. Record the average values as the first number over the second number, for example, "120 over 90."

A. What do you think each of these values represents? T/I

B. Record your blood pressure in a class table. Are all the values the same? Why do you think there is variation among individuals? T/I A

C. What problems did you experience in using the sphygmomanometer and stethoscope? How did you overcome these problems? T/I

11.1 The Need for a Circulatory System

What do all living things require to go on living? Recall from previous studies that all living things must obtain and use nutrients, get rid of waste, interact with their environment, and perform other processes.

Unicellular organisms perform all of the processes necessary for life using only a single cell. Most multicellular animals, on the other hand, require organ systems to carry out life processes. In these complex multicellular animals, cells organize into tissues, tissues into organs, and organs into organ systems.

The circulatory, digestive, respiratory, and other organ systems all rely on each other in order to function properly. The circulatory system is responsible for transporting (or circulating) nutrients, dissolved gases, wastes, and other chemicals to and from individual cells in an organism.

The Need for Circulation

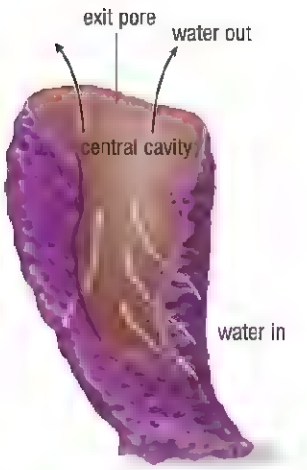


Figure 1 Circulation in the sponge is achieved by setting up a current that pulls water in through the body pores and out through the top opening.

Not all organisms need a circulatory system. Unicellular organisms, such as bacteria, some algae, and some fungi, are in direct contact with their environment. A circulatory system is not necessary to transport gases through these organisms. For most of these organisms, gases such as oxygen and carbon dioxide diffuse across the cell membrane. Unicellular organisms do not require the transport of nutrients either. For example, some unicellular organisms engulf other cells to obtain their nutrients, and some simply absorb organic molecules.

Some simple multicellular animals also do not need a circulatory system. Sponges, for example, consist of a body that has only two cell layers (**Figure 1**). The cells that line the body cavity have flagella that beat to circulate water through the cavity. As the water passes over the cells, oxygen is absorbed, nutrients are trapped, and carbon dioxide and wastes are eliminated. Because the body is only two cell layers thick, all the body cells are close enough to the external environment to allow for exchange of substances. In a single day, a sponge can move a volume of water 20 000 times its body volume. The water in its central cavity is completely flushed about every 4.3 s, bringing in oxygenated water and suspended nutrients.

The need for a circulatory system arose as an evolutionary adaptation to increasing body size. In larger and more complex multicellular animals, some body cells do not come into contact with the fluids of the external environment—air or water. Individual body cells in a multicellular animal are in a fixed position and have no means of moving around. A circulatory system ensures that oxygen and nutrients are delivered to every cell. A circulatory system also allows waste products that are removed from cells to be released into the external environment.

All of the cells of organisms must be surrounded by a fluid. This fluid provides the medium for diffusion of gases, nutrients, and wastes. In unicellular and simple multicellular animals, cells are directly in contact with the fluid of the external environment. In more complex animals, individual cells are surrounded by tissue fluid, which enables diffusion of substances.

The Functions of a Circulatory System

The circulatory system has several functions. It delivers oxygen from the respiratory system, nutrients from the digestive system, hormones from the endocrine system, chemicals or cells from the immune system, and metabolic wastes from the cells to the lungs and kidneys. In warm-blooded animals, the circulatory system also plays a role in distributing thermal energy throughout the body to maintain body temperature. You will learn about how the circulatory system is designed to carry out these functions as you progress through this chapter.

Types of Circulatory Systems

Although circulatory systems vary among animals, all circulatory systems have three fundamental features:

- a fluid that transports (circulates) materials through the body
- a network of tubes in which the fluid circulates
- a pump that pushes the fluid through the tubes

Different species of animals have either an open or a closed circulatory system, depending on the animals' size and complexity.

LEARNING TIP

Word Roots
The prefixes *hem-*, *hemo-*, and *hemato-* mean "of or relating to the blood." For example, hemoglobin is a blood protein. Hematology is the study of blood.

Open Circulatory Systems

Most invertebrates, such as snails, insects, and crustaceans, have an open circulatory system. In an open circulatory system the circulating fluid is pumped into an interconnected system of body cavities, or sinuses, where it bathes the cells directly (**Figure 2**). The circulating fluid, called **hemolymph**, is a mixture of blood and tissue fluid. Contraction of one or more hearts forces the hemolymph out of the circulatory tubes, called blood vessels, through the sinuses. When the heart relaxes, the hemolymph is drawn back to the heart through open-ended pores. Body movements can also help in the circulation of hemolymph.

hemolymph a mixture of blood and tissue fluid that is the circulating fluid in an open circulatory system

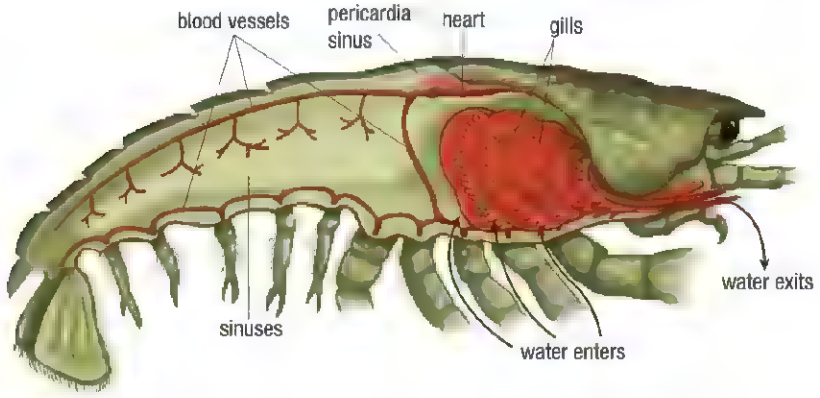


Figure 2 The lobster has an open circulatory system that distributes hemolymph through the sinuses.

To understand how an open circulatory system works, try visualizing an airtight bucket filled with water (**Figure 3**). Two hoses are inserted through holes in the side of the bucket. The other ends of the hoses are connected to a squeeze bulb that forces liquid in only one direction. As the bulb (heart) squeezes, the fluid (hemolymph) is forced through one hose (blood vessel) into the bucket (sinus). The fluid in the bucket is forced into the other hose (blood vessel) and back to the bulb (heart).

The hemolymph is under low pressure and circulates slowly through the body. This low pressure makes the open circulatory system relatively inefficient; however, an open circulatory system is appropriate for certain animals. Many animals with an open circulatory system have a low metabolic rate, so they do not need to eat often. This low metabolic rate is important because diffusion is limited by slow blood flow in these animals. Nevertheless, some animals, such as the bumblebee, with a high metabolic rate have an open circulatory system. In these animals the open circulatory system is efficient at cooling the body by dissipating the thermal energy produced during metabolism.

Not all open circulatory systems are used for transporting oxygen. Insects, for example, have a separate system of branching air tubes that deliver oxygen to all parts of the body. The main functions of the insect circulatory system are to transport nutrients and other chemicals to the cells, as well as to transport waste products out of the cells.

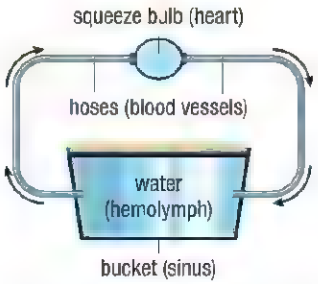


Figure 3 A model of an open circulatory system

Closed Circulatory Systems

All vertebrates, as well as some invertebrates, such as earthworms, squids, and octopuses, have closed circulatory systems. In a closed circulatory system the fluid (often blood) is contained within a network of tubes, or blood vessels. This system separates blood from the tissue fluid by keeping the blood enclosed in the vessels. The tissue fluid surrounds the cells and provides a medium for diffusion of substances from the bloodstream to the cells. In contrast, in an open circulatory system, a mixture of blood and tissue fluid flows through the blood vessels and sinuses.

Considerable variation has evolved in closed systems. The earthworm, for example, has five pairs of aortic arches, which are enlarged blood vessels. The aortic arches work like hearts by contracting to pump the blood through the system (**Figure 4**).

Fish have a closed circulatory system consisting of a single continuous loop, or circuit. The circuit carries blood to the gills. At the gills, the blood takes in oxygen from the surrounding water and releases carbon dioxide to the water (**Figure 5**). From the gills, blood circulates to the rest of the body, delivering oxygen and removing carbon dioxide. The heart of a fish has two chambers: an atrium and a ventricle. The **atrium** (plural: atria) receives the collected blood from the body and pumps it into the ventricle. The **ventricle** then contracts to pump the blood to the gills and around the body.

atrium a chamber of the heart that receives blood from the body

ventricle a chamber of the heart that pumps blood to the body

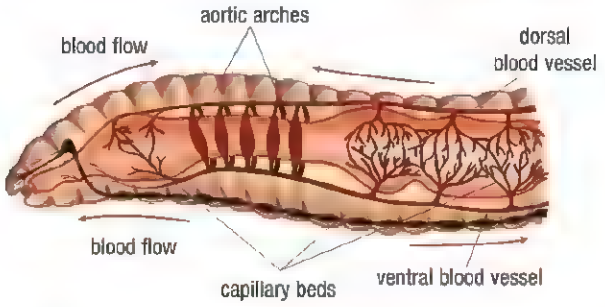


Figure 4 The blood of an earthworm is enclosed within a system of blood vessels.

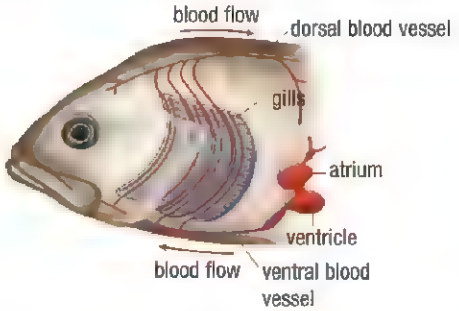


Figure 5 The circulatory system of fish is a single circuit. Blood is pumped through the gills, where it is oxygenated, and then pumped throughout the body.

FROM SIMPLE TO COMPLEX

The heart evolved from the simple aortic arches of ancient invertebrates to the two-chambered heart that is found in fish (**Figure 6(a)**). As more time passed, the heart further evolved to the three-chambered heart that amphibians possess. The heart of amphibians has two atria and a single ventricle (**Figure 6(b)**). The left atrium receives oxygenated blood from the lungs and skin. The right atrium receives deoxygenated blood from the body. The single ventricle pumps blood to both the lungs and the body. In most reptiles, such as snakes and lizards, the ventricle of the heart is partially separated into two areas by a wall of tissue called the **septum** (**Figure 6(c)**). In mammals, birds, and crocodilians, the septum is complete and separates the tip of the heart into a left and right ventricle, resulting in a four-chambered heart (**Figure 6(d)**).

septum a wall of tissue that divides a body cavity or structure into smaller parts; for example, the ventricle of a mammal's heart is divided into two cavities by a septum

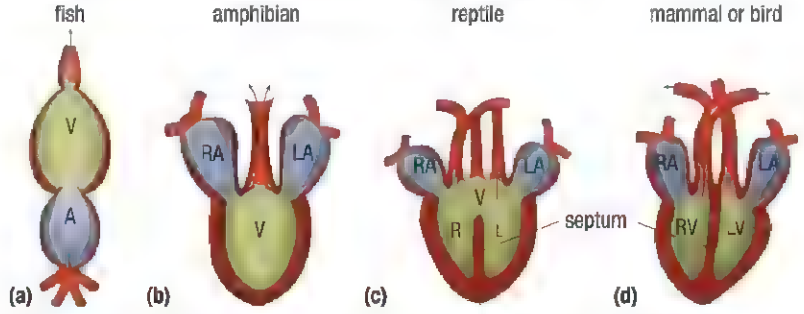


Figure 6 As animals evolved in size and complexity, the heart evolved from a simple two-chambered structure to a four-chambered structure. In this diagram, A represents atrium, V represents ventricle, R represents right, and L represents left.

TWO-CIRCUIT CIRCULATORY SYSTEM

Mammals, along with birds and crocodilians, developed a more complex closed circulatory system. The main difference is the evolution of a two-circuit system in which circulation to the lungs is separated from circulation to the rest of the body. This separation of the circuits is possible because of the structure of the heart. The four chambers create a double pump where the two circuits intersect. The **pulmonary circuit** circulates blood to the lungs for gas exchange with the external environment. The **systemic circuit** circulates blood around the body to deliver oxygen, nutrients, and other substances to the body cells, and to pick up carbon dioxide (**Figure 7**).

A four-chambered heart has two ventricles that pump blood from the heart and two atria that receive blood returning to the heart. One atrium receives oxygenated blood from the lungs, while the other atrium receives deoxygenated blood from the body. Likewise, one ventricle pumps deoxygenated blood to the lungs, while the other pumps oxygenated blood to the body.

pulmonary circuit the part of the circulatory system that delivers blood to the lungs

systemic circuit the part of the circulatory system that delivers blood around the body

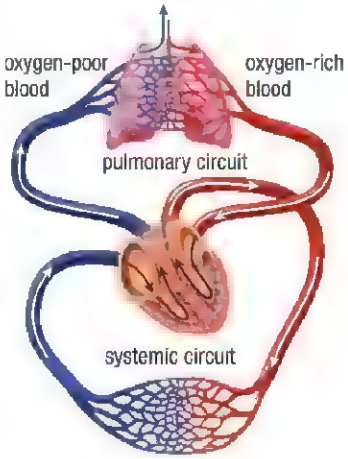


Figure 7 The mammalian circulatory system is a two-circuit system.

11.1 Summary

- Unicellular and simple multicellular organisms do not need a circulatory system. They obtain the materials they need through direct contact of their cell(s) with the external environment.
- The development of a circulatory system is an evolutionary adaptation to an increase in size and complexity.
- Circulatory systems vary in structure, but all have three features in common—a fluid, a network of tubes, and a pump (heart). The two main functions of the circulatory system are transport and protection.
- In open circulatory systems the circulating fluid, or hemolymph, is a mixture of blood and tissue fluid. In closed circulatory systems the blood is confined by a network of blood vessels and is separate from the tissue fluid.
- The circulatory system of fish consists of a single circuit with a two-chambered heart. Mammals, birds, and crocodilians have a two-circuit system consisting of a pulmonary circuit (circulating to the lungs) and a systemic circuit (circulating to the rest of the body).
- Mammals, birds, and crocodilians have a four-chambered heart that permits the separation of the pulmonary and systemic circuits.

Investigation 11.1.1

Fetal Pig Dissection (page 510)
Make note of the types of c rculatory systems you have read about in this section. At the end of this chapter, you will have an opportunity to dissect a fetal pig and observe the structures of a typical mammalian circulatory system.

11.1 Questions

1. Why do more complex multicellular animals require a circulatory system? K/U
2. What are the functions of the circulatory system? K/U
3. What three features are common to all circulatory systems? K/U
4. (a) Use a graphic organizer to compare and contrast the similarities and differences between an open circulatory system and a closed circulatory system. Give at least one example of an organism with each type of circulatory system.
   (b) Why can insects and other invertebrates survive with an open circulatory system? K/U C
5. (a) Explain the difference between the pulmonary circuit and the systemic circuit.
   (b) What structural feature of the heart makes a two-circuit system possible? Explain. K/U A
6. You have already learned that the digestive system relies on the circulatory system for the distribution of nutrients to the cells of the body. How do you think the digestive system contributes to the functioning of the circulatory system? T/I A
7. Use the Internet and other sources to research the evolution of the heart from two chambers to four chambers. Write a brief summary of your research, including the reason for the evolution and the advantages of the four-chambered heart. K/U C

GO TO NELSON SCIENCE

11.2 Blood: A Fluid Tissue

Humans have long recognized the importance of blood, even without understanding the true nature of its role in the body. Modern science has shown that blood is fundamental to life. Blood delivers oxygen and nutrients to, and transports wastes away from, the cells of the body.

Figure 1 Centrifuged donor blood

What Is in Blood?

Depending on the size of the individual, the human body contains from 4 L to 5 L of blood. Blood is a connective tissue—a tissue that consists of cells suspended in an intercellular matrix. In humans blood consists of two main components. The cellular component includes red blood cells, white blood cells, and platelets. The intercellular matrix is a yellow-coloured liquid called plasma. The components of blood can be separated by spinning the blood in a centrifuge (**Figure 1**). The densest component—red blood cells—settles to the bottom. The plasma, being the least dense component, rises to the top. The platelets and white blood cells form a thin layer in the middle.

Plasma

Plasma is a protein-rich liquid in which blood cells and platelets are suspended. Over 90 % of plasma is water. Dissolved or suspended in the plasma are a variety of substances: oxygen, proteins, and nutrient molecules such as glucose, minerals, and vitamins, along with carbon dioxide and other waste products of cellular respiration.

The blood proteins present in plasma include albumins, globulins, and fibrinogen, each of which has a special role. The concentration of albumins in plasma determines the amount of water entering or leaving the bloodstream by osmosis. This helps to balance the amount of water within the body and maintain the appropriate volume of blood. The globulins transport lipids, cholesterol, some fat-soluble vitamins, and some minerals. One type of globulin, the immunoglobulins (or antibodies), are part of the immune response that helps fight many infectious diseases, including bacterial and viral infections. Fibrinogen plays a critical role in blood clotting. Plasma that has fibrinogen and other clotting factors removed is referred to as **serum**.

serum the fluid that results when the cells, platelets, and fibrinogen have been removed from whole blood

Plasma also carries a number of dissolved ions: Na^+, K^+, Ca^{2+}, Cl^-, and HCO_3^-. The components of ordinary table salt, sodium ions (Na^+) and chlorine ions (Cl^-), are the most common ions. Similar to albumin, a high concentration of sodium ions in the plasma creates an osmotic pressure gradient and causes water to enter the bloodstream. As more water enters the blood, the total volume of the blood increases and the blood pressure increases. This helps explain the connection between a high-salt diet and hypertension (high blood pressure).

Cellular Component

The cellular component of blood consists of red blood cells, white blood cells, and platelets.

RED BLOOD CELLS—FOR TRANSPORT

erythrocyte a red blood cell

Red blood cells, or **erythrocytes**, have a peculiar shape: they are biconcave disks—meaning that they are concave on both sides (**Figure 2**). The disk shape of erythrocytes is advantageous because it has 20 % to 30 % greater surface area for gas exchange than a sphere of the same volume. Erythrocytes are tiny. Lined up side by side, 135 erythrocytes would measure approximately 1 mm!

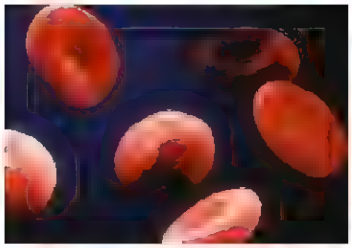


Figure 2 Red blood cells are the most common type of blood cell.

The main function of erythrocytes is to carry oxygen from the lungs to the body cells, and to carry carbon dioxide from the body cells back to the lungs to be expelled. Recall from Chapter 10 that oxygen diffuses from the air in the alveoli into the bloodstream. Oxygen attaches to the hemoglobin molecules in the erythrocytes. Oxygen is transported by the erythrocytes around the body and diffuses from the blood into the tissue fluid, and from the tissue fluid into each cell.

Erythrocytes are formed from stem cells in the marrow of the vertebrae, ribs, breastbone, skull, and bones of the arms and legs. While erythrocytes are developing in the marrow, they have a nucleus. As they mature and are released into the bloodstream, the nucleus breaks down and disappears. This increases the available space for hemoglobin and, in turn, the ability of the erythrocytes to carry oxygen.

Like all cells, erythrocytes eventually die. After about 120 days in circulation, they die and are removed in the liver and spleen. Between 2 million and 3 million erythrocytes are produced each second to replace those that are removed. The appropriate number of erythrocytes in the body is maintained by a feedback system. If the oxygen level in the blood falls below a certain level, the brain signals the production of a hormone, erythropoietin (EPO), in the kidneys. This hormone stimulates the production of additional erythrocytes in bone marrow.

WHITE BLOOD CELLS—FOR PROTECTION

White blood cells, or **leukocytes**, are also formed in bone marrow. Unlike erythrocytes, there are several different types of leukocytes, all of which have nuclei. Leukocytes are one of the first lines of defence against harmful bacteria, viruses, and other organisms that can cause diseases.

There are two categories of leukocytes—granular and agranular. Granular leukocytes have granules (small particles, or grains) in their cytoplasm. The types of granular leukocytes are neutrophils, eosinophils, and basophils. The granules contain different chemicals that attack foreign material and microorganisms that are brought into the cells. Leukocytes are attracted to the site of an infection or injury and kill bacteria in the area.

Agranular leukocytes, called lymphocytes and monocytes, are specialized for engulfing bacteria and other microorganisms. Some lymphocytes also produce antibodies that attack invading microorganisms or their toxins. Monocytes, which enlarge to become macrophages, are the largest leukocytes and are excellent scavengers. Macrophages clean up bacteria, dead cells, and other debris in the bloodstream and tissues (**Figure 3**).

Many leukocytes use phagocytosis to destroy bacteria or harmful substances. Phagocytosis involves engulfing the bacteria or harmful substance within the cell membrane. Once the cell has engulfed its target, enzymes are released and destroy the target and the leukocyte itself. The remnants of the leukocyte and whatever it engulfed are left behind as a whitish substance known as **pus**. Pus at the site of a cut or other break in the skin, such as a pimple (**Figure 4**), is a sign that your defences are working to combat infection.

leukocyte a white blood cell

Figure 3 Macrophages are very efficient at destroying bacteria.

Figure 4 A pimple forms when a hair follicle becomes infected.

PLATELETS—FOR PROTECTION

A break in a small blood vessel would be a relatively minor event for the body and would cause a minor bruise. A break in a larger blood vessel might cause an individual to bleed to death if it were not for the blood's second protection mechanism: clotting. **Platelets** are small cell fragments produced from stem cells in bone marrow. Platelets are essential in blood clotting, or coagulation.

When a blood vessel is broken, chemicals in the platelets cause the platelets to stick to collagen fibres in the blood vessel wall. As more and more platelets stick to the fibres, a clot is created to seal the hole in the blood vessel. Once the temporary clot is in place, the clotting process continues below the surface. Fibrinogen in the plasma is converted into long strands of fibrin, forming a mesh that traps more platelets and blood cells (**Figure 5**). This permanent clot stops the leakage of blood and allows time for the injury to heal. Over time, the blood clot is absorbed by the body.

While blood clots are a very important safety feature of the circulatory system, there are some associated risks. A clot that becomes dislodged from the site of an injury can move through the blood vessels and block the flow of blood in some other part of the body. For example, a clot that moves into a blood vessel in the brain and blocks the flow of blood can cause a stroke. Depending on its location in the brain, tissue that has been damaged by lack of oxygen during a stroke can lead to physical and mental disabilities.

pus a yellowish-white fluid formed in infected tissue, consisting of white blood cells and cellular debris

platelet a cell fragment in the blood that is necessary for blood clotting

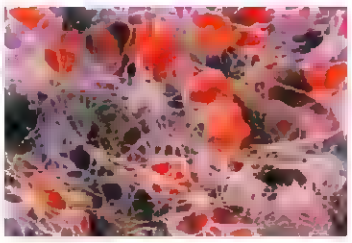


Figure 5 A blood clot

anemia a condition of a low erythrocyte count or a low hemoglobin level, which leads to low oxygen levels

CAREER **LINK**

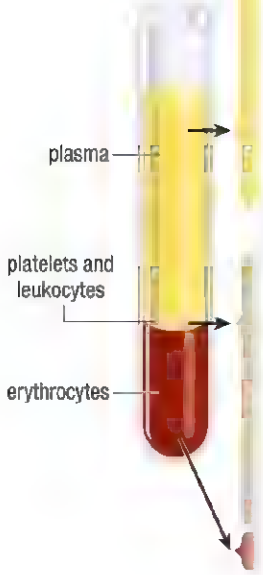
Hematologist

One of the roles of a hematologist is to analyze complete blood counts or other properties of blood to identify potential diseases or disorders related to the blood. To learn about becoming a hematologist,

GO TO NELSON SCIENCE

Counting Blood Cells

If you have ever had a blood sample taken, one of the tests that the doctor likely asked to have performed was the complete blood count, or CBC. A machine called a hemocytometer is used to estimate the number of erythrocytes, leukocytes, and platelets in a particular volume of blood. There is an acceptable or normal range of values for each cell type (**Figure 6**). Values falling outside this range signal that further tests should be done to determine if a medical problem exists. For example, a lower than normal erythrocyte count indicates that a person has a condition known as anemia. The amount of oxygen delivered to the cells is diminished in a person with **anemia**, and he or she may feel tired and run down. Anemia is commonly caused by bleeding from an external injury or from internal bleeding, such as from an ulcer in the stomach. Anemia may result from a variety of diseases, but the most common cause is a deficiency of iron in the diet. Iron in the heme groups enables oxygen to attach to the hemoglobin molecules.



Components	Relative amounts	Functions
Plasma portion (55 %–58 % of total volume):		
Water	91 %–92 % of plasma volume	Solvent
Plasma proteins (albumin, globulins, fibrinogen, and so on)	7 %–8 %	Defence, clotting, lipid transport, roles in extracellular fluid volume, and so on
Ions, sugars, lipids, amino acids, hormones, vitamins, dissolved gases, urea and uric acid (metabolic wastes)	1 %–2 %	Roles in extracellular fluid volume, pH, eliminating waste products, and so on
Cellular portion (42 %–45 % of total volume):		
Platelets	250 000–300 000 per microlitre	Roles in clotting
Leukocytes (white blood cells)		
Neutrophils	3000–6750	Phagocytosis during inflammation
Lymphocytes	1000–2700	Immune response
Monocytes/macrophages	150–720	Phagocytosis in all defence responses
Eosinophils	100–360	Defence against parasitic worms
Basophils	25–90	Secrete substances for inflammatory response and for fat removal from blood
Erythrocytes (red blood cells)	4 800 000–5 400 000	Oxygen, carbon dioxide transport

Figure 6 Each component of blood has an acceptable range of values representing its proportion of the total volume. Each blood cell type has a normal range of numbers. The various components of the blood have specific functions.

A higher than normal leukocyte count is a sign that the body is fighting an infection. It is also one of the symptoms of leukemia, a form of cancer of the blood and bone marrow. In this disease the cancerous leukocytes grow and survive better than normal cells and interfere with the production of other leukocytes, erythrocytes, and platelets.

Blood Types

Blood transfusions are common and reasonably safe procedures today, but it was not always so. The first blood transfusions did not have a very high success rate; some patients recovered without any ill effects, whereas others died. The reason for the deaths was not understood until 1901, when Karl Landsteiner discovered that there were different blood types and that some types were incompatible. Successful transfusions depend on proper matching of the blood types.

Recall from Chapter 5 that there are four blood types: type A, type B, type AB, and type O. Blood types are determined by the presence (or absence) of different sugars, called markers, on the cell membranes of erythrocytes. There are two markers: A and B. Type A blood has the A marker, and type B blood has the B marker. Individuals with both markers present have type AB blood, and individuals with neither marker have type O blood.

Incompatibility occurs because the markers act as antigens, which are considered foreign material. When the immune system detects antigens, it produces antibodies that attach to the antigens. This causes the blood cells to clump together, blocking blood vessels and preventing the circulation of blood and delivery of oxygen. For example, if type A blood is transfused into a person with type B blood, the recipient will develop antibodies in response to the type A marker. Type A blood can be transfused into a person with type A or type AB blood because their blood already has the A marker and will not produce antibodies against it.

Because type O blood has neither marker, transfusion of type A, B, or AB blood into an individual with type O blood will induce an antibody response. People with type O can receive only type O blood. However, because it has no markers, type O blood can be transfused into individuals of any blood type. A person with type O is said to be a universal donor.

Type AB is the opposite of type O; it has both protein markers and is compatible with any type of donated blood. A person with type AB is known as a universal recipient. However, type AB blood can only be transfused to another type AB person.

You learned in Chapter 5 that blood type is an inherited trait. However, this does not mean that your blood type is automatically compatible with your parents' blood type. Depending on their blood type, you may be able to donate or receive blood from one, both, or neither of your parents.

WEB LINK

For more information on different blood types and blood transfusions,

GO TO NELSON SCIENCE

The Rhesus Factor

There is another inherited factor, called the rhesus factor, which affects the compatibility of blood types. The rhesus factor was discovered by studying the blood of rhesus monkeys. The rhesus factor is an antigen on erythrocyte membranes that produces an antibody reaction. This is not as severe as the antibody reaction to blood type markers. The rhesus antigen is present in approximately 85 % of the population, and these individuals are said to be Rh-positive. In the remaining 15 % of the population, the rhesus antigen is not present, and these individuals are referred to as Rh-negative. Individuals with Rh-negative blood may donate their blood to, but should not receive blood from, individuals with Rh-positive blood. It is always best to mix blood of the same type and rhesus factor.

WEB LINK

To learn more about the discovery of the rhesus factor, and the role of the rhesus monkey,

GO TO NELSON SCIENCE

Blood Substitutes and Artificial Blood

During emergencies when blood transfusions are needed, the supply of blood may not always be adequate or totally safe. Researchers are attempting to develop a blood substitute that will solve these problems. Most of the research is focused on the transport function of blood, that is, its ability to carry oxygen and carbon dioxide, rather than on the more complex protection roles of blood. An ideal blood substitute must

- not induce an antibody reaction in the recipient
- eliminate, or greatly reduce, the possibility of transmitting infections
- be capable of delivering adequate oxygen
- be readily available, capable of being stored at room temperature, and have a long shelf life

Including all of these qualities make the task of developing a blood substitute very challenging, and there has been limited success to date.

Research has focused on two types of artificial blood: hemoglobin-based oxygen carriers (HBOCs) and perfluorocarbon emulsions (PFCEs). HBOCs may contain human or cow blood. The problem with using HBOCs is that hemoglobin has a toxic effect on the kidneys when it is outside the protective environment of erythrocytes. PFCEs are totally synthetic. Fluosol, a PFCE-based product, was the first and only artificial blood approved for medical use. However, because there were some adverse effects and the results were marginal, it was removed from the market in 1994. Although Fluosol was not successful, research continues in the field of PFCEs.

UNIT TASK BOOKMARK

Consider what you have learned about blood, in particular blood cell count. How can this information help you as you complete the Unit Task?

11.2 Summary

- The main components of blood are plasma and the cellular component, which includes red and white blood cells and platelets.
- The primary function of red blood cells, or erythrocytes, is to transport oxygen. Erythrocytes contain hemoglobin, which increases the amount of oxygen that can be carried in the blood. White blood cells, or leukocytes, are an important part of the immune system. Platelets initiate blood clotting.
- The proportion of each component and the number of each type of cell in a specific volume of blood should fall within an acceptable range. Values outside this range may indicate a health problem.
- Blood type incompatibility occurs when the donor blood has a marker but the recipient blood does not. The marker induces an antibody reaction in the recipient's blood.
- A person with blood type O is a universal donor, and a person with blood type AB is a universal recipient
- The rhesus, or Rh, factor is an antigen that also affects compatibility. Rh-positive individuals carry the antigen; Rh-negative individuals do not.
- Research is being conducted in developing a product that can carry out the oxygenation function of red blood cells.

11.2 Questions

1. (a) What are the two main functions of blood?
   (b) Create a table or other graphic organizer to describe the components of blood and their functions. K/U C
2. How are erythrocytes different from other cells of the body? K/U
3. Create a diagram like the one shown in **Figure 7** and apply the following labels: serum, blood, plasma. Explain your choices. K/U T/I C

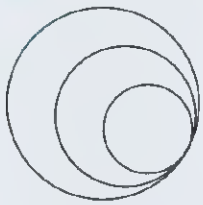


Figure 7

4. Describe the process of blood clotting. What risk is associated with blood clotting? K/U
5. What information is provided in a complete blood count? How can this information be used? K/U A
6. Emergency vehicles may carry O-negative blood for use at the scene of an accident. Explain why this is a common practice. K/U T/I A
7. Create a table or use a graphic organizer to summarize the compatibility of each ABO blood type and rhesus factor with other blood types. K/U C
8. (a) How is artificial blood different from real blood?
   (b) What are the advantages of artificial blood over real blood? K/U A
9. Another approach to solving the problem of available blood for transfusion is called "antigen camouflaging." Use the Internet and other sources to research antigen camouflaging. Write a report describing how antigen camouflaging works and what advantages it has over artificial blood. T/I C
10. Use the Internet and other sources to research available blood substitutes and the Canadian position on them. What are the major stumbling blocks to approval in Canada? T/I A

GO TO NELSON SCIENCE

Blood Vessels

11.3

If you could join together all of the blood vessels in your body in a straight line, they would reach from St. John's, Newfoundland and Labrador, to Victoria, British Columbia, and back, twice! End to end, they would span about 19 000 km. Our blood vessels are not one long tube but a complex network of tubes that branch and rebranch. The largest blood vessel in the body is about 3 cm in diameter, slightly larger than the diameter of a regular garden hose. The smallest blood vessels are about 5 μm to 10 μm in diameter, just wide enough for blood cells to pass through in single file. **Figure 1** shows the major blood vessels in the human body.

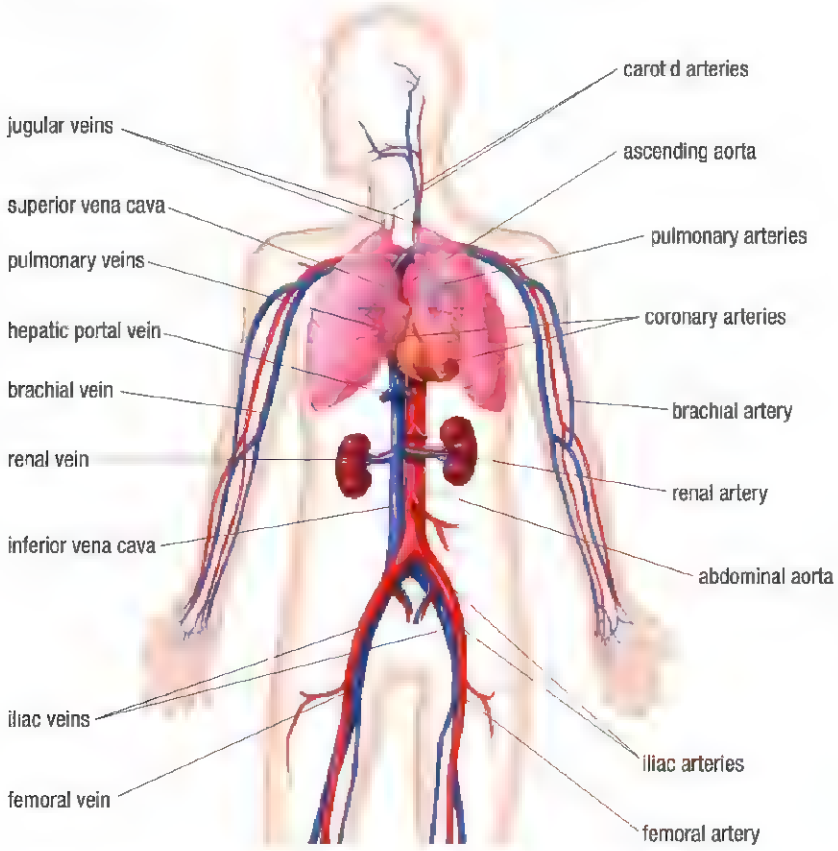


Figure 1 The major arteries and veins of the human circulatory system

Arteries

A blood vessel that carries blood away from the heart toward the body tissues is called an artery. A single large artery, called the **aorta**, leaves the heart. It branches into major arteries that carry blood around the body (refer back to Figure 1).

The walls of arteries have three layers of tissue—an outer layer of connective tissue, a middle layer of smooth muscle, and a smooth inner single layer of epithelial cells called the endothelium (**Figure 2**). When the ventricles of the heart contract to pump blood around the body, the arteries expand slightly in diameter to accommodate the increased pressure of the blood within them. The outer layer of the arteries includes elastin fibres that give the vessels elasticity. When the ventricles relax, the walls of the arteries return to their original size, pushing the blood farther into the downstream vessels. The elasticity of the artery walls ensures that there is a continuous flow of blood through the blood vessels, even when the heart is relaxed.

aorta the largest blood vesse in the body, connected directly to the heart; the aorta branches into arteries that carry oxygenated blood to the body tissues

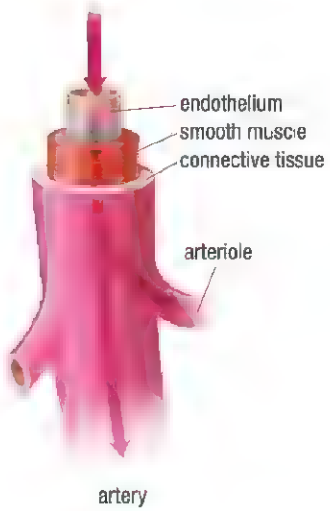


Figure 2 The three ayers of tissue in the artery prov de a strong but elastic tube that can withstand the pressure of the flu d it carries.

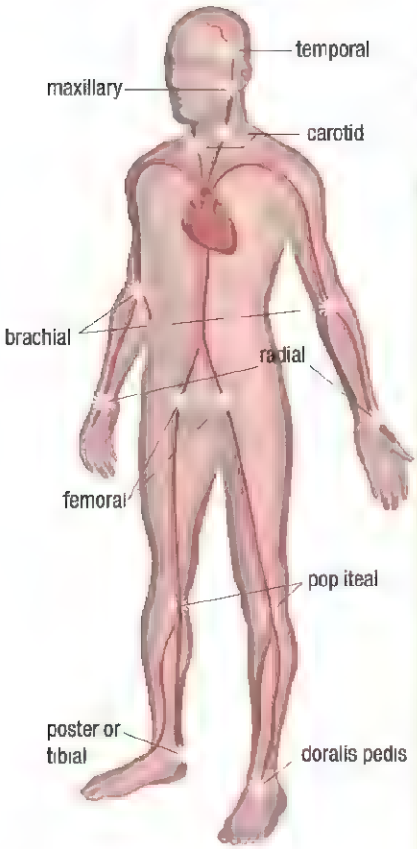


Figure 3 Pulse points are located where an artery runs close to the surface of the body.

When blood is forced through the artery by the contraction of the heart, the artery expands. This expansion can be felt as the pulse if the artery is fairly large, close to the skin, and in front of a bone or other firm structure. Taking the pulse is a simple but very useful procedure in determining the heart rate. The pulse can be taken at a number of locations, called pulse points, on the body (**Figure 3**).

Mini Investigation

Taking a Pulse

Skills: Performing, Observing, Analyzing SKILLS HANDBOOK A2.1

The techniques for taking the pulse are simple and straightforward when you know the locations. The most common point is the radial artery in the wrist. The purpose of this activity is to find your pulse at several different pulse points and determine your heart rate. The main reason for taking a pulse is to measure the heart rate.

Equipment and Materials: stopwatch

1. Find your pulse at the radial artery. The radial artery runs along the thumb side of your wrist as shown in **Figure 4**.

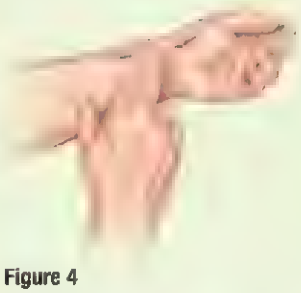


Figure 4

2. Count the number of beats in 15 s and multiply by 4 to obtain your heart rate. Record your heart rate.
3. Refer to Figure 3 and try to find your pulse at other accessible locations.

A. Why do you think the radial artery is the most commonly used pulse point? T/I A

B. Did you have difficulty finding other pulse points? Why do you think it was more difficult in other locations? T/I A

C. When police or medical personnel check for signs of life, they check the carotid pulse. Why do you think they check this pulse rather than the radial pulse? T/I A

Arterioles

arteriole the smallest artery, with smooth muscle in its walls

The arteries that branch from the aorta further branch and rebranch into the smallest arteries, which are called **arterioles**. Because the arterioles have smooth muscle in their walls, they can be controlled by the nervous system. Signals from the nerves can regulate the diameter of the arterioles and control the blood flow to certain parts of the body.

CONTROLLING BLOOD FLOW IN ARTERIOLES

Have you ever wondered why your skin looks red or flushed when you are overheated? In certain situations (such as when the body is overheated), nerve impulses cause the smooth muscle in the arterioles in the skin to relax. This relaxation increases the diameter of the blood vessel, which allows an increased flow of blood to the skin and produces a flushed look. This is a cooling strategy: warm blood close to the surface of the skin loses thermal energy to the surrounding environment. The relaxation of the smooth muscle, which increases the diameter of blood vessels, is known as **vasodilation**. If the body is cold, the opposite happens. **Vasoconstriction** occurs when nerve impulses cause the smooth muscle in the arterioles to contract, narrowing the diameter of the blood vessel and restricting the blood flow. Restricting blood flow to the skin prevents thermal energy loss to the environment.

vasodilation an increase in the diameter (dilation) of arterioles that increases the blood flow to tissues

vasoconstriction a decrease in the diameter of arterioles that decreases the blood flow to tissues

Vasoconstriction is an important feature of the circulatory system. Without it, you would need about 200 L of blood to fill all of the blood vessels in the body. The ability to control blood flow ensures that the 5 L of blood you have is distributed where it is needed. When you are resting, for example, your muscles do not require much blood. Constriction of the arterioles diverts blood away from the muscles to other areas of the body where blood is required. During exercise, muscles require lots of blood, so blood flow to the lungs and muscles is increased, while it is reduced to other parts of the body such as the stomach and intestines.

Capillaries

When an arteriole reaches the tissues of the body, it branches further into smaller blood vessels called capillaries. The capillaries form networks of blood vessels that supply oxygen and nutrients to every cell throughout the body tissues. The capillaries merge in a kind of mirror image of the way they branched from the arterioles, forming larger blood vessels on the opposite (or venous) side of a capillary network (**Figure 5**).

The capillary networks are so extensive that no body cell is farther than two cells away from a capillary. The walls of the capillaries are only a single cell layer thick. Through these very thin walls, oxygen and nutrients diffuse from the blood into the tissue fluid that surrounds the cells. Likewise, carbon dioxide and other waste materials produced during aerobic cellular respiration diffuse into the tissue fluid and then into the capillaries.

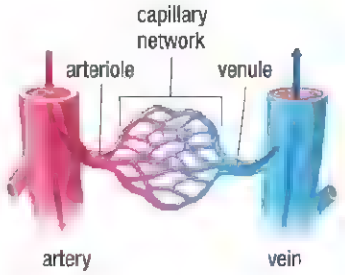


Figure 5 Arteries branch into arterioles before branching off further, into capillary networks.

Fluid Exchange

Differences in pressure and water concentration are responsible for the exchange of fluids in the capillary networks. Higher fluid pressure on the arterial side of a capillary network causes water to diffuse from the blood into the tissue fluid. This reduced concentration of water in the blood increases the concentration of dissolved substances and proteins in the blood as it crosses the capillary network. On the venous side of the capillary network, the concentration of water in the blood is less than the concentration of water in the tissue. This difference in concentration moves some of the water from the tissue fluid to the blood. The remainder of the water enters the lymphatic system. This exchange of fluids maintains a balance between fluids in the circulatory system and in the tissues.

Controlling Blood Flow in Capillaries

Since there is no smooth muscle in the walls of capillaries, the diameter of the capillaries cannot be controlled by the nervous system. However, there are pre-capillary sphincter muscles where the arteriole branches into a capillary. These sphincter muscles serve the same function as the dilation and constriction of arterioles. If blood is not needed in a particular capillary network, the pre-capillary sphincters contract and reduce blood flow (**Figure 6**). During exercise, for example, the arterioles and sphincters are fully relaxed, and the blood flow to the muscles is increased.

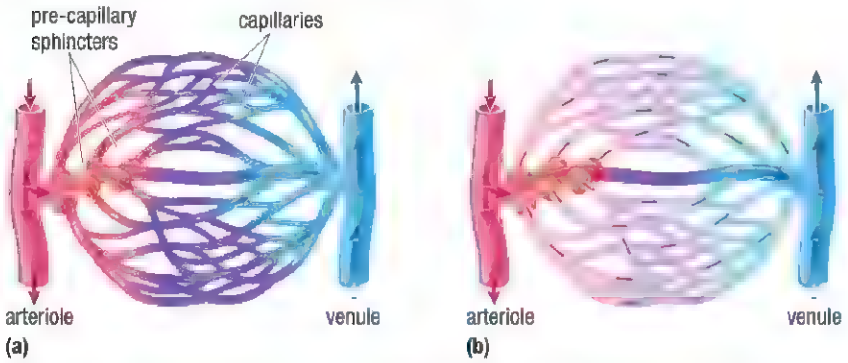


Figure 6 (a) Pre-capillary sphincter muscles are relaxed and blood flow through the capillary network is at a maximum. (b) The sphincter muscles are contracted, allowing minimal blood flow through the capillary network.

Capillaries are so small in diameter that blood cells move through them in single file. You might think that this would increase the pressure and cause the blood to flow faster. However, when blood leaves an arteriole and flows into a network of capillaries there is a significant decrease in the rate at which the blood flows. This is because the millions of capillaries in a network create a total cross-sectional area that is much greater than the cross-sectional area of the arterioles and the artery from which the capillaries branch (**Figure 7**). Think of this as a fast running stream (the artery) flowing into a much larger pool (a capillary network). As the water enters the pool, the current slows considerably. This slower flow through the capillary network is important because it provides time for the diffusion of substances into and out of the capillaries.

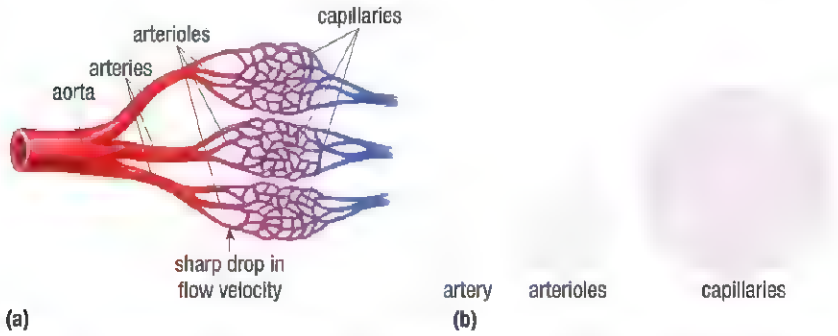


Figure 7 (a) Capillaries are much smaller in diameter than arteries or arterioles. (b) The cumulative cross-sectional area of a capillary network is much greater than that of even the largest arteries, resulting in a decrease in flow velocity.

Venules and Veins

venule the smallest vein; formed by the merging of capillaries

The capillary networks in body tissues are a dividing region. On one side are the arteries and arterioles carrying oxygenated blood and nutrients to the tissues. On the other side, the capillaries merge into small vessels called **venules** that merge to form larger vessels called veins. Venules and veins carry deoxygenated blood containing carbon dioxide and other waste products from the body tissues. (The one exception is the capillary networks in the lungs, where the blood is oxygenated.) After passing through the capillary networks, the blood begins its journey back to the heart.

Veins have a different structure from arteries. The middle layer of smooth muscle is not as thick as in arteries, and the walls are not as elastic (**Figure 8**). As a result, the internal diameter of veins is greater than that of arteries. When a fluid moves from a smaller-diameter tube to a larger-diameter tube, the pressure is reduced. Blood pressure in veins is significantly lower than in arteries. How then does blood get back to the heart, especially from the lower parts of the body?

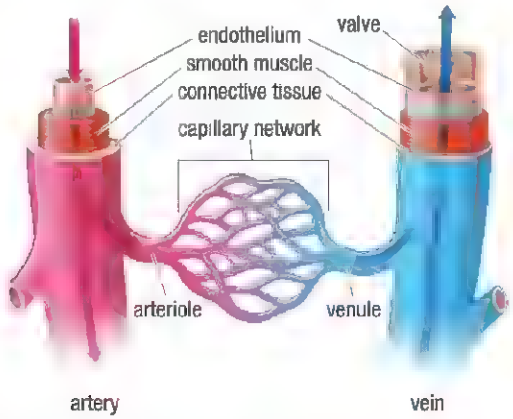


Figure 8 Because of the higher pressure, the walls of arteries are thicker than those of veins.

Many of the larger veins have valves that ensure the blood flows in only one direction. The skeletal muscles also help the circulation of blood. When these muscles contract, they squeeze the veins. This increases the pressure in the veins and, in conjunction with the valves, helps push the blood back toward the heart (**Figure 9**).

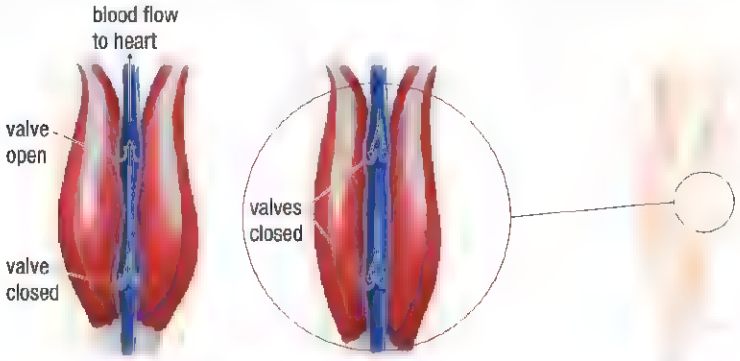


Figure 9 The contraction of the muscles squeezes the veins, and the valves keep the blood flowing in the right direction.

Despite the help of valves and skeletal muscles, blood tends to pool in the lower extremities, especially after standing or sitting for a long period of time. You may have heard of military personnel fainting after standing at attention for a long period of time. In this situation, the skeletal muscles in the lower body do not move or contract enough to allow the blood to return to the heart. Most of the blood pools in the lower body, and circulation to the brain is decreased to the point where the individual faints. Blood pooling in the legs also increases the likelihood of clot formation.

As people age, their veins and other blood vessels tend to become less elastic. Individuals who have spent long periods of time standing or sitting may damage the valves in the veins of the lower legs. If the valves are not functioning properly, there is a greater accumulation of blood in the veins and the veins stretch but do not rebound, creating a bulging condition known as varicose veins (**Figure 10**).

Figure 10 Varicose veins

Blood Pressure

The pulse is evidence that the arteries swell when the heart contracts. Blood is under pressure in the blood vessels because of the pumping of the heart. The pressure increases when the heart contracts and decreases when the heart relaxes.

The overall volume of blood is a significant factor in determining blood pressure. Since blood is contained within the circulatory system, it exerts pressure on the walls of the circulatory system. This pressure is known as blood pressure.

A specific volume of blood can be accommodated within the confines of the circulatory system. If the amount of fluid increases, the pressure on the walls of the blood vessels will increase. Because the blood vessels are somewhat elastic, some increase in blood volume can be tolerated. The total available volume increases slightly as the blood vessels stretch. The elasticity of the blood vessel walls exerts an opposite force on the blood. This opposite force results in an increase in blood pressure. When the blood vessels are stretched to the limit, the increase in blood pressure poses more serious health risks.

Blood pressure is measured with an instrument called a sphygmomanometer. It consists of an inflatable cuff that is wrapped around the arm and a gauge or display that indicates the pressure of the blood in the brachial artery. The cuff is inflated until the blood flow in the brachial artery is stopped. As the pressure is released from the cuff, pressure sensors in the cuff detect the vibrations of the blood flowing through the artery. The first reading is the **systolic pressure**, which is the pressure in the artery when the heart contracts. Normal systolic pressure in a young adult is about 120 mm Hg. (The SI unit of pressure is the kPa, but blood pressure is still measured in millimetres of mercury, or mm Hg. One kPa is equal to 7.5 mm Hg and 1 mm Hg = 0.133 kPa.)

systolic pressure the blood pressure in the arteries when the heart contracts

diastolic pressure the blood pressure in the arteries when the heart relaxes

The second reading of the sphygmomanometer is taken when the heart is relaxed and blood is flowing through the artery. This is called the **diastolic pressure**. Normal diastolic pressure in a young adult is about 80 mm Hg. The blood pressure is reported as 120/80 (read as 120 over 80) and means that the individual has a systolic pressure of 120 mm Hg and a diastolic pressure of 80 mm Hg. Blood pressure is not the same throughout the circulatory system. Blood pressure decreases as blood flows away from the heart to the veins and back to the heart (**Figure 11**). The greatest drop in pressure is when the blood flows from the arteries to the arterioles and capillaries.

Investigation 11.3.1

The Effect of Exercise on Heart Rate and Blood Pressure (page 513)

Now that you have read about blood pressure, you can complete Investigation 11.3.1.

In this investigation you will design and conduct a controlled experiment to determine whether and how heart rate and blood pressure are affected by exercise.

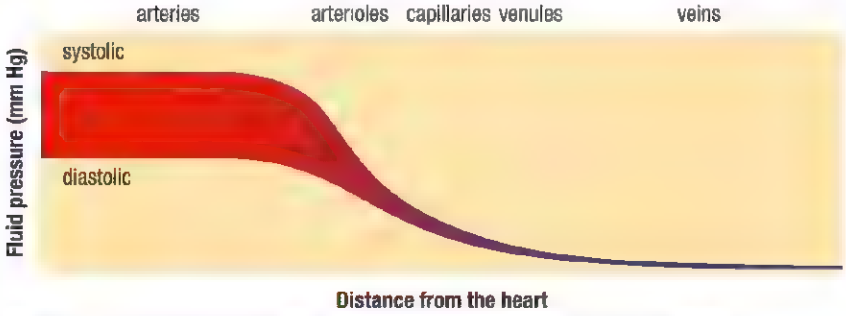


Figure 11 By the time the blood gets back to the heart, it is under very low pressure.

Hypertension

Many factors can influence blood pressure. The diameter of the blood vessels, an individual's level of physical activity, temperature, body position, diet, stress, age, and medications can cause variations in blood pressure.

hypertension consistent blood pressure above the range of normal values; also called high blood pressure

There is an acceptable normal range of systolic and diastolic blood pressures. Blood pressures consistently above the normal levels constitute a condition called **hypertension**, commonly known as high blood pressure. Hypertension can be caused by a variety of medical or lifestyle conditions. Kidney disease, for example, can cause more fluid to be retained in the blood, causing an increase in the volume of blood and a resulting increase in blood pressure. Some medications can also cause high blood pressure. Age is a very important contributing factor. As an individual ages, the walls of blood vessels lose some of their elasticity and cannot stretch as much as they once did. Since the available volume of the circulatory system does not increase, the pressure within the system increases.

Nutrition Facts

Serving Size 1/4 Cup (30g)
Servings Per Container About 38

Amount Per Serving	
Calories 200 Calories from Fat 150	
	% Daily Value*
Total Fat 17g	**26%**
Saturated Fat 2.5g	**13%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 120mg	**5%**
Total Carbohydrate 7g	**2%**
Dietary Fiber 2g	**8%**
Sugars 1g	
Protein 5g	

Vitamin A 0% • Vitamin C 0%
Calcium 4% • Iron 8%
*Percent Daily Values are based on a 2,000 calorie diet

Figure 12 Nutrition labels indicate the amount of sodium and the percentage of the recommended daily allowance.

Diets that are very high in sodium (salt) create high levels of sodium in the blood because the kidneys cannot eliminate the excess. The increased sodium concentration in the blood causes water to move into the blood by osmosis. This may lead to an increase in blood volume and an elevated blood pressure. On average, Canadians consume more than twice the recommended upper level of 2300 mg of sodium per day. Nutrition labels indicate how much sodium is contained in a portion of the food and what percentage of the recommended daily value it represents (**Figure 12**).

Hypertension has been labelled "the silent killer" because it usually does not show any recognizable symptoms until a serious event, such as a heart attack or stroke, occurs. Hypertension is dangerous because it forces the heart to work harder to pump blood around the body. It can also result in ruptured blood vessels in organs such as the kidneys and eyes. High blood pressure can be reduced by adjusting the individual's lifestyle—following a more appropriate diet, losing weight, and getting regular exercise. If these approaches do not work, medications are available to reduce blood pressure through vasodilation or by reducing the amount of retained water in the blood.

The Lymphatic System

The lymphatic system has two major roles: one in the circulatory system and the other in the immune system. As part of the circulatory system, the lymphatic system helps ensure that the blood volume is maintained. As part of the immune system, the lymphatic system filters bacteria and other components from the blood.

As blood circulates through the capillaries, some proteins leak from the blood into the tissue fluid. This lowers the pressure of the tissue fluid, and some fluid moves from the blood into the tissue fluid by osmosis. The excess tissue fluid is collected in lymph vessels and returned to the blood in the veins. Lymph vessels are distributed throughout the body (**Figure 13**). Once the fluid is in the lymph system, it is known as **lymph**. This process is one of the mechanisms that maintains a balance of fluids in the circulatory system and ensures that the blood volume remains relatively stable. Were it not for this system, the body tissues would swell because of the extra tissue fluid.

lymph tissue fluid collected in lymph vessels and returned to the blood

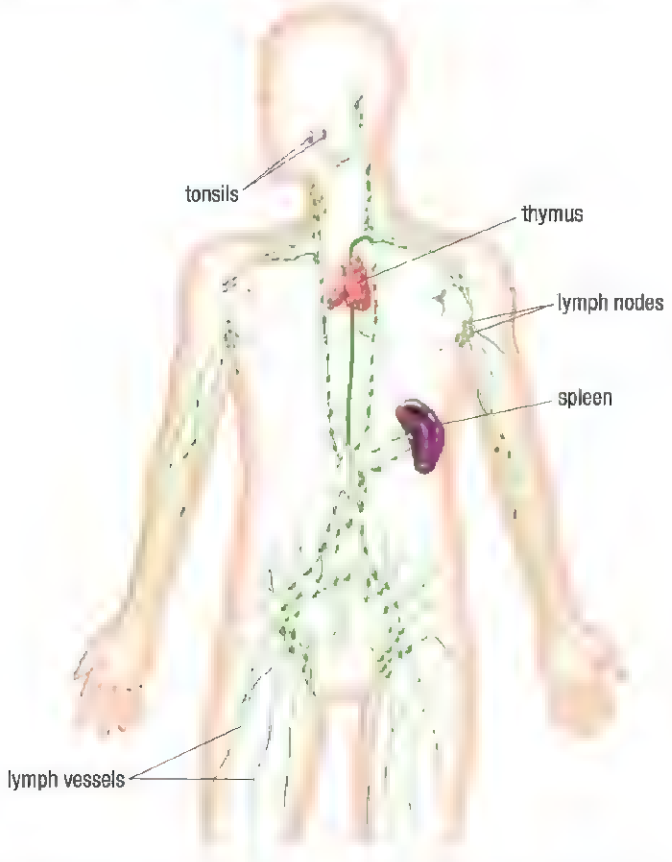


Figure 13 The lymph system ensures that excess tissue fluid is collected and returned to the circulatory system. The lymph nodes act as filters for the blood.

Lymph contains a variety of components—the fluid itself, bacteria and other foreign cells, dead or damaged cells, and fat molecules absorbed through the lacteals in the villi of the small intestine. These components are either delivered back into the bloodstream or filtered from the system and removed.

Removal of bacteria or other harmful cells from the blood is part of the defensive role of the lymphatic system. Scattered through the system are **lymph nodes**, where leukocytes gather to destroy disease-causing viruses, bacteria, and other microorganisms. Swollen and painful lymph nodes are a sign that the immune system is fighting a serious infection.

lymph node an enlargement in the lymph vessels that acts as a filter to remove bacteria and foreign particles

The **spleen** is the largest organ of the lymphatic system. It serves as a filtering station and as a reservoir of erythrocytes and leukocytes. When required, the body draws on this reservoir to fight diseases by providing additional leukocytes, or to increase oxygen delivery by providing additional erythrocytes. The tonsils also serve a similar function by filtering out bacteria, viruses, and other materials. Tonsils often become infected and inflamed, a condition known as tonsillitis. The infected tonsils become red and swollen, in order to work better to trap or stop the disease-causing bacteria. Tonsillitis begins with a sudden sore throat and painful swallowing. A serious infection of the spleen or tonsils often requires surgical removal.

spleen the largest organ of the lymphatic system; acts as a filter and a reservoir of erythrocytes and leukocytes

thymus a glandular organ of the lymphatic system; secretes hormones to promote the maturity of lymphocytes

The **thymus** is a critical organ of the immune system. The thymus secretes hormones that help lymphocytes, a type of leukocyte, develop their ability to recognize and attack specific foreign invaders. These lymphocytes are an essential line of defence against bacteria, viruses, and other disease-causing agents.

UNIT TASK BOOKMARK

Consider what you have learned about blood vessels and blood pressure. How can this information help you as you create a health and fitness profile in the Unit Task?

11.3 Summary

- Arteries and arterioles are blood vessels that carry blood away from the heart. Arteries have a layer of smooth muscle in their walls. Vasoconstriction reduces the diameter of arteries and decreases blood flow. Vasodilation relaxes the muscle and increases blood flow.
- The pulse is the expansion of an artery in response to the increased pressure caused by the contraction of the heart.
- Capillaries are the smallest blood vessels. The capillary networks in the tissues are the locations where the exchange of materials takes place.
- Blood pressure and flow rate decrease significantly when blood enters the capillary networks in the tissues. This provides time for the diffusion of materials into and out of the blood.
- Veins and venules are blood vessels that carry blood back to the heart after it passes through the capillary networks in the tissues. Because blood pressure is low in the veins, valves and the contraction of skeletal muscles help move the blood back to the heart.
- Blood pressure, measured with a sphygmomanometer, is reported as two values: systolic pressure (the pressure in the arteries when the heart contracts) and diastolic pressure (the pressure in the arteries when the heart relaxes).
- Hypertension, commonly known as high blood pressure, is a condition in which the blood pressure is consistently higher than normal.
- The lymphatic system has two primary functions—to return excess fluids from the tissue fluid to the bloodstream and to protect the body by filtering and destroying bacteria and other microorganisms.

11.3 Questions

1. Use a T-chart to identify three differences between arteries and veins. K/U C
2. (a) What is a pulse?
   (b) What information can you gather from taking a pulse? K/U K/U
3. How does gravity affect the circulation of blood? What structures in the blood vessels are designed to counteract the effect of gravity? K/U
4. What type of blood vessel do you think is shown in **Figure 14**? Explain your answer. K/U K/U

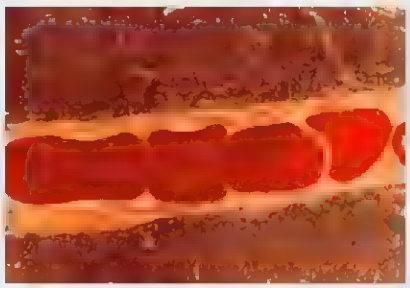


Figure 14

5. Explain why the rate of blood flow decreases in the capillary networks. Why is this an advantage? K/U A
6. Nicotine is a drug that acts as a vasoconstrictor. Would a smoker likely have high blood pressure or low blood pressure? Explain why. K/U T/I A
7. Analyze the available nutrition labels on the packages of the foods you ate yesterday. Estimate how much sodium you consumed. Describe the possible effects of consuming too much sodium. T/I C A
8. Use the Internet and other sources to research and report on the social and economic costs of hypertension. Consider loss of work hours, cost of medical treatment, loss of quality of life, etc. Prepare a presentation outlining the costs of this disorder. T/I C
9. Briefly describe the two primary functions of the lymphatic system K/U
10. Suggest and explain two possible effects of the removal of the spleen. K/U T/I A

GO TO NELSON SCIENCE

The Cardiac Cycle and Circulation

11.4

Phrases such as "the old ticker" and "regular as clockwork" are commonly used when talking about the heart and the heartbeat. They refer to the regular rhythmic beating of the heart that we are, for the most part, unaware of. In Section 11.1, you learned about the four-chambered, two-circuit circulatory system of mammals. In this section, you will examine the structure of the human heart more closely, look at circulation in the two-circuit system, and investigate normal and abnormal heart rhythms.

The Structure of the Heart

The human heart is the remarkable, muscular organ at the centre of the circulatory system (**Figure 1**). Despite the common misconception that the heart is on the left, it is located in the middle of the chest, directly under the breastbone.

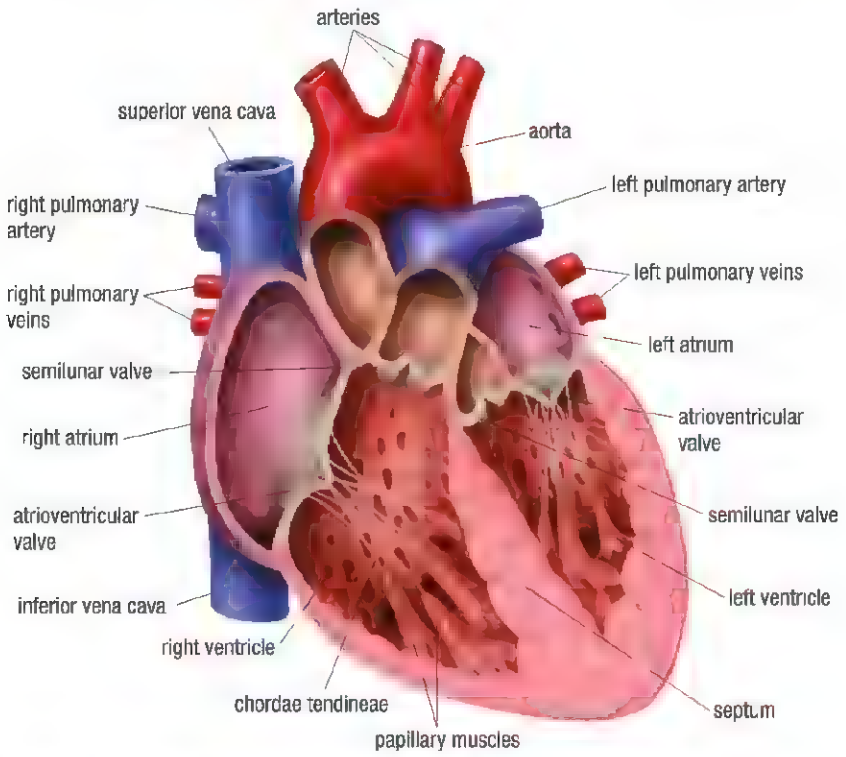


Figure 1 The human heart is a four-chambered double pump. The "left" and "right" in the labels refer to the left and right of the individual whose heart is represented in this diagram

A wall of muscle called the septum separates the heart into two parallel pumps, each with an atrium and a ventricle. The atria, located at the top of the heart, receive blood and pump it into the ventricles. The ventricles, located at the bottom of the heart, pump blood out into two circuits: the pulmonary circuit and the systemic circuit. The right side of the heart circulates blood to the pulmonary circuit, that is, to the lungs. The left side of the heart receives this blood and pumps it out through the systemic circuit, or the rest of the body.

The muscular walls of the ventricles are much thicker than the walls of the atria because the ventricles have to pump the blood over much longer distances and through capillary networks. The layers of muscles in the ventricles are arranged spirally around the heart. Contraction of these muscles produces a slight twisting motion that wrings the blood out of the ventricles.

LEARNING TIP

Root Words
The words "cardiac" and "coronary" both mean "of or related to the heart." Cardiac comes from *kardia*, the Greek word for "heart." Coronary comes from *corona*, the Latin word for "crown."

There are not many materials, natural or synthetic, as durable or resilient as human heart muscles. Each beat requires the contraction and relaxation of the heart muscles. On average, your heart beats over 100 000 times per day, about 37 million times per year, and more than 2.5 billion times in your lifetime. To appreciate this, clench and open your fist as many times as you can at about the same rate as your heart beats. How long can you keep doing it before you have to stop?

pericardium a two-layered fluid-filled membrane that surrounds the heart and prevents friction between the heart and other tissues and organs

The heart is surrounded by the **pericardium**, a two-layered connective tissue membrane that has fluid between the two layers. This fluid filled membrane protects the heart from friction with other tissues and organs in the thoracic (chest) cavity as the heart beats.

coronary blood vessel a blood vessel that circulates blood to and from the muscle cells of the heart

Since the heart is a muscular organ that works continuously, it has a high demand for oxygen and nutrients. It is estimated that the heart requires over 10 % of the total oxygen load of the blood, proportionally much higher than any other muscle of the same size. Even when the body is at rest, the heart requires eight times as much oxygen as a comparable mass of skeletal muscle. The heart has its own supply of blood vessels, known as the **coronary blood vessels**. This network of arteries and veins provides oxygen and nutrients to the muscle cells of the heart and removes the waste products. The coronary arteries branch from the aorta. The coronary veins join to form the coronary sinus, which empties directly into the right atrium.

Circulation

The heart is a very efficient circulation pump. When the body is resting, the heart can pump about 5 L of blood in one minute—a volume equal to the total volume of blood in the body. At its maximum output, it can pump more than 25 L/min. The following paragraph traces the circulation of blood through the heart, starting with blood that arrives at the heart from the body. Refer to **Figure 2** as you follow the path of the blood.

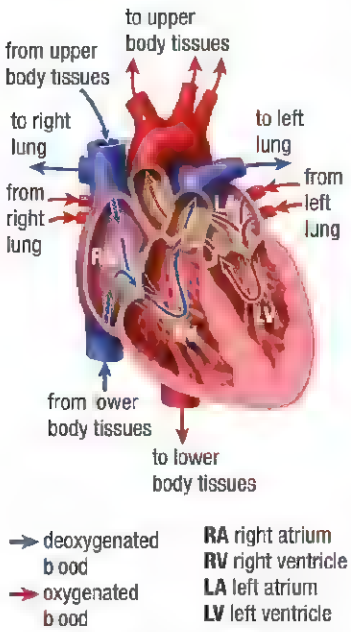


Figure 2 The path of blood through the circulatory system

Deoxygenated blood from the body enters the right atrium of the heart. Contraction of the right atrium, along with the pull of gravity, forces the blood into the right ventricle. The right ventricle contracts to force the blood out through the pulmonary arteries to the lungs. Oxygen diffuses into the blood as it passes through the capillary networks in the lungs. The oxygenated blood from the lungs enters the left atrium through the pulmonary veins. The left atrium contracts and squeezes blood into the left ventricle. The left ventricle contracts and forces blood out through the aorta, the largest blood vessel in the body. The aorta branches into major arteries that carry blood around the body. As blood passes through the capillary networks in the body tissues, oxygen diffuses out of the blood into the cells. After passing through the tissues, the deoxygenated blood enters the venules, which merge to form veins. These veins, in turn, merge to form larger veins. The largest veins, the inferior vena cava and the superior vena cava, enter the right atrium of the heart. The vena cava veins collect blood from the upper and lower parts of the body and return it to the right atrium. The cycle begins again.

semilunar valve the valve located between the left ventricle and the aorta and the right ventricle and the pulmonary arteries to prevent the backflow of blood when the ventricles relax

Four valves in the heart ensure that blood flows in only one direction. Two of the valves are located where the ventricles meet the pulmonary arteries and the aorta. These valves are called the **semilunar valves**, named because they are shaped like half moons (Figure 1, page 495). The semilunar valves prevent blood from flowing back into the ventricles when the ventricles relax.

atrioventricular valve the valve located between each atrium and ventricle to prevent the backflow of blood from the ventricles to the atria

chordae tendineae tendons that support the atrioventricular valves

The other two valves, the **atrioventricular valves**, are located between the atria and the ventricles, as the name suggests (Figure 1, page 495). The left atrioventricular valve has two flaps and is sometimes called the bicuspid valve. The right atrioventricular valve has three flaps and is also known as the tricuspid valve. The two atrioventricular valves prevent blood from flowing from the ventricles back into the atria when the ventricles contract. Because atrioventricular valves are subjected to higher pressures than the semilunar valves, they are supported by tough cords known as the **chordae tendineae**. The chordae tendineae are attached to papillary muscles on the inside of the ventricles. Contraction of these muscles and tension in the chordae tendineae prevent the valves from opening backwards into the atria during the high pressure caused by the ventricular contraction.

The Cardiac Cycle

The **cardiac cycle** refers to a complete heartbeat—a contraction and relaxation of each chamber of the heart. Under normal conditions, a cardiac cycle takes about 0.8 s. The above description of the circulation through the heart is sequential for the sake of clarity. The contractions and relaxations of the chambers of the heart occur in a specific sequence, but there is overlap in the various phases, making the cardiac cycle a very complex event.

cardiac cycle the contractions and relaxations of the heart muscles during a complete heartbeat

The cardiac cycle is usually divided into two basic phases: diastole and systole. **Diastole** is the period of relaxation and filling of the heart with blood. **Systole** is the period of contraction and emptying of the heart. **Figure 3** shows a complete cardiac cycle divided into five additional stages. Diastole begins when the relaxed atria begin to fill with blood (stage 1 of Figure 3). As the atria fill, the pressure pushes the atrioventricular valves open, and blood begins to fill the relaxed ventricles (stage 2 of Figure 3). As the atria continue to fill, the muscular walls of the atria contract, and the ventricles completely fill with blood (stage 3 of Figure 3).

diastole the period of the cardiac cycle when the ventricles are relaxed; blood fills the ventricles

systole the period of the cardiac cycle when the ventricles contract; blood is ejected from the ventricles

Once the ventricles are completely filled with blood, they contract (stage 4 of Figure 3). This contraction of the ventricles marks the beginning of systole. The increasing pressure forces the atrioventricular valves shut, pushing blood through the semilunar valves and into the arteries (stage 5 of Figure 3).

The ventricles then begin to relax, and the volume in the ventricles increases. With increased volume, pressure in the ventricles begins to decrease. Blood is prevented from re-entering the ventricles (which are now an area of lower pressure) by the closing of the semilunar valves (return to stage 1 of Figure 3).

WEB LINK

To view an animation and learn more about the cardiac cycle,

GO TO NELSON SCIENCE

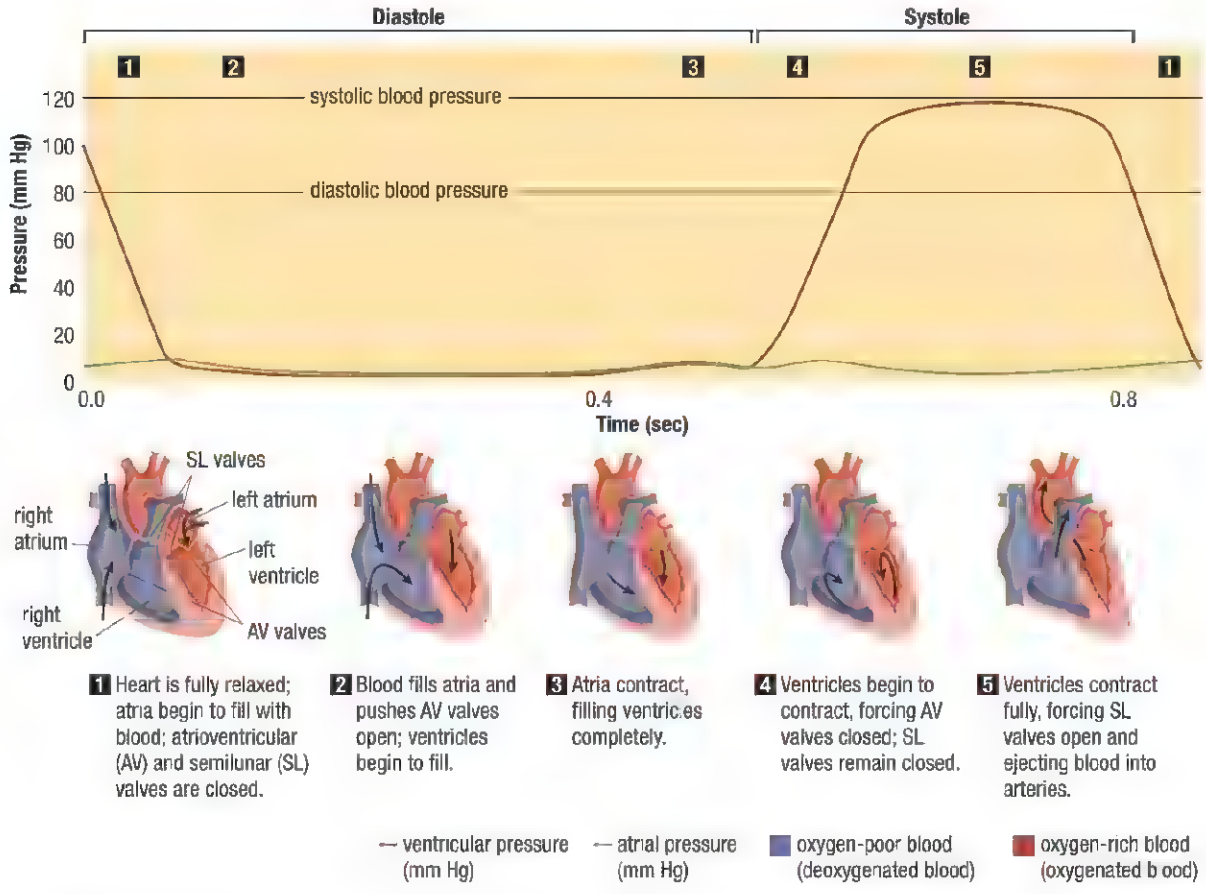


Figure 3 The cardiac cycle

Heart Sounds

The familiar *lubb-DUBB* sound of the heartbeat is caused by the closing of the heart valves. The first sound occurs when the atrioventricular valves close as the ventricles begin to contract. This is a double sound because the left valve closes slightly before the right valve. This is the *lubb* sound. The second sound, the *DUBB* part, occurs as the ventricles relax and the semilunar valves snap shut, preventing blood from flowing back into the ventricles.

Heart sounds can be clearly heard using the most familiar medical instrument, the stethoscope. The stethoscope is a simple but important tool for doctors. It can be used to listen to the normal sounds of the heart, but, more importantly, it can also be used to detect abnormal sounds. For example, if a heart valve fails to close properly or completely, the sound of blood leaking past or through the valve can be heard. This condition is known as a heart murmur, so named because of the sound that is heard. While murmurs are not usually life threatening, they do result in some blood flowing back to the atria or ventricles and a degree of inefficiency in delivering oxygen to the tissues. Individuals with heart murmurs have an increased heart rate that helps compensate for the decreased blood flow through the heart.

Mini Investigation

Listening to Heart Sounds

Skills: Observing, Analyzing, Communicating SKILLS HANDBOOK A2.1, A3.5

In this activity you will listen to your own heartbeat and to recordings of normal and abnormal heart sounds.

Equipment and Materials: stethoscope; alcohol towelette; recordings of heart sounds, mp3 or wav player; computer with speakers

1. Use an alcohol towelette to clean the earpieces of the stethoscope.
2. Place the stethoscope on your chest and listen for your heartbeat. You do not have to place the stethoscope directly on the skin to hear your heartbeat. You can listen through a thin shirt. Find and note the location where the sound is the loudest.
3. Perform moderate exercise, such as walking or stepping in place, for 1 min to 2 min. Listen to your heart again. Record your observations.
4. Obtain the recordings of normal and abnormal heart sounds from your teacher or from the website provided by your teacher. Record your observations.

A. Draw a sketch of your chest and indicate on the sketch where the heart sounds are clearest. T/I C

B. Describe how the heart sounds are different after exercise. T/I

C. Identify the abnormal condition(s) and describe how the sounds differ from the normal sounds. T/I

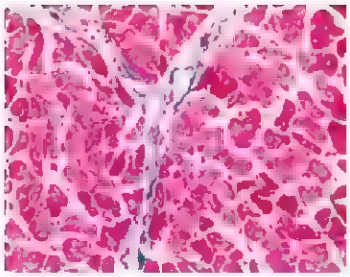


Figure 4 Cardiac muscle cells have a complex branching pattern, which enables the muscle to withstand the forceful contractions of the heart

myogenic muscle muscle that can contract and relax without input from an external source

Regulation of Heart Rhythm

Experiments have shown that when a heart is removed from a live animal, it continues to beat for a short time. These observations led to the conclusion that the stimulus for the heart muscle contraction must be within the muscle itself. Unlike skeletal muscle, which must be stimulated by signals through nerves, heart muscle has the unusual ability to contract and relax on its own, without stimulation from an external source. This type of muscle is known as **myogenic muscle** (**Figure 4**). These muscles are a safety mechanism that ensures that the heart will continue to beat even if the nervous system is damaged. This explains why the heart continues to beat in a person who has severe brain injury or has been pronounced "brain dead."

The heartbeat is initiated in a cluster of cells in the right atrium called the **sinoatrial (SA) node** (**Figure 5**). This small mass of nerve and muscle cells generates between 50 and 100 electrical signals per minute in a regular pattern. The SA node acts as a pacemaker, and its signals set the normal rhythm of the heartbeat. The electrical signals first pass over the atria in a wave, causing the muscles to contract. The signals then reach a second mass of cells called the **atrioventricular (AV) node**, located in the wall of the heart between the right atrium and right ventricle. From the AV node, special conducting fibres, called **Purkinje fibres**, run down through the septum and throughout the muscle cells of the ventricles.

Although the heart has a self-contained nervous system responsible for maintaining the heartbeat, the heart rate can be adjusted by the sympathetic and parasympathetic nervous systems. The sympathetic nervous system is the part of the nervous system that controls processes in the body in preparation for stress. It is often referred to as the "fight or flight" system. The parasympathetic nervous system, often referred to as the "rest and digest" system, is the part of the nervous system that conserves energy by relaxing muscles in the heart and digestive system.

In preparation for stress, signals from the brain through the sympathetic nervous system cause the heart rate to increase. The increased heart rate increases the flow of blood and the supply of oxygen to areas of the body where it is needed. When the stress is no longer present, the brain sends signals through the parasympathetic nervous system and the heart rate returns to normal. Heart rate can be affected by many factors, including emotional stress, physical stress such as being overweight, physical activity, drugs such as caffeine and nicotine, and various medical conditions.

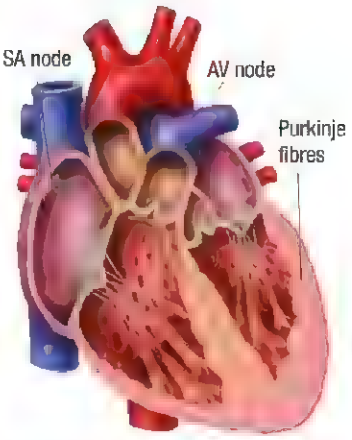


Figure 5 The heart has its own system for conducting electrical stimuli from the SA node to the muscle cells.

sinoatrial (SA) node a mass of muscle and nerve cells in the right atrium; initiates the heartbeat and maintains the regular rhythm

atrioventricular (AV) node a mass of conducting cells that transmits the signals from the SA node to the muscles of the ventricles

Purkinje fibre a conducting fibre that carries the electrical signals from the AV node to the muscle cells of the ventricles

Observing the Heartbeat

As early as 1786, Luigi Galvani was studying the effects of electricity on animal tissues. He learned that stimulation of the nerves in a dissected frog's leg caused the leg muscles to contract. His name is associated with the galvanometer, an instrument used to detect and measure electrical current. In 1791, Galvani progressed to studying the reaction of the frog's heart muscle to electrical stimulation. In 1887, a British physiologist named Augustus Waller discovered that you could detect the electrical current from the heart from various places on the skin. This is the basis of modern electrocardiography.

Since the heartbeat is electrically stimulated, it can be indirectly observed by measuring the strength and duration of its electrical signals with an instrument called an **electrocardiograph**. The electrocardiograph measures the electrical signals and records them as an electrocardiogram. Both an electrocardiograph and an electrocardiogram are referred to as an ECG (also commonly referred to as an EKG); the context indicates whether the reference is to the machine or to the recording.

electrocardiograph a device that detects the electrical activity of the heart through electrodes placed on the body's surface

The electrocardiograph is connected to the body using a number of electrodes, usually 12. These electrodes are sensitive to the small variations in potential difference caused by the electrical signals in the heart. The variations in the voltage cause a marker needle to deflect. The strength of the current determines how much the needle is deflected. The ECG tracing is recorded on paper that moves under the needle as it is deflected (**Figure 6**).

Figure 6 An ECG tracing showing the strength and duration of the electrical signals from the heart. Each repeating pattern represents one heartbeat.

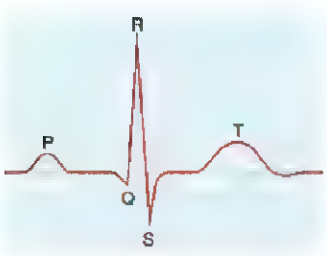


Figure 7 A single heartbeat shown on the ECG includes the P wave, the QRS complex, and the T wave.

Analyzing the Heartbeat

Analysis of an electrocardiogram can provide evidence for the presence of abnormal heart conditions. Abnormalities can be identified only by comparing the potential problem with the normal ECG pattern (**Figure 7**). A normal heartbeat starts with an electrical stimulus from the SA node. This stimulus spreads and causes the contraction of the atria, creating the P wave on the ECG. The signal also travels to the AV node, during which there is a very brief delay in transmission of the signal. The QRS complex follows, during which the electrical stimulus moves via the Purkinje fibres to the tip of the ventricles. The contraction of the ventricles starts at the tip of the heart and spreads upward, producing the squeezing action that forces the blood out into the aorta and pulmonary arteries. After the QRS complex, there is another slight delay as the ventricles recover and prepare for the next contraction. The recovery period produces the T wave on the ECG.

11.4 Summary

- The human heart is a four-chambered double pump that pumps blood through two separate circuits: the pulmonary circuit and systemic circuit.
- Two atrioventricular valves and two semilunar valves in the heart ensure that blood flows in only one direction.
- The cardiac cycle has two main phases—diastole and systole. Diastole begins when the ventricles begin to relax and ends when the ventricles are filled with blood. Systole begins when the ventricles begin to contract and ends when the blood is forced out of the ventricles.
- Heart sounds, which can be heard with the use of a stethoscope, are produced by the closing of the heart valves.
- Cardiac muscle is myogenic, which means it can contract and relax without input from external nerve stimuli. The rate of contraction and relaxation, however, can be adjusted by the nervous system.
- The sinoatrial (SA) node initiates the heartbeat by sending electrical signals and maintains the regular rhythm of contraction and relaxation.
- An electrocardiograph can be used to monitor the cardiac cycle. The printout from the electrocardiograph, called an electrocardiogram, can be analyzed to diagnose abnormal heart conditions.

Investigation 11.4.1

Analyzing and Interpreting ECGs (page 514)

Now that you have read about the cardiac cycle you can complete Investigation 11.4.1.

In this investigation you will analyze normal and abnormal ECGs to determine the heart rate and strength, and to propose possible diagnoses of abnormal heart conditions.

UNIT TASK BOOKMARK

Consider what you have learned about the cardiac cycle. How can this information help you as you create a health and fitness profile in the Unit Task?

11.4 Questions

1. Explain why there is a difference in the thickness of the walls of the atria and the walls of the ventricles. K/U A
2. Explain the importance of the coronary blood vessels. K/U
3. Why do the atrioventricular valves have chordae tendineae while the semilunar valves do not? K/U A
4. Describe briefly what happens during diastole and systole. K/U
5. The heartbeat is generally described as a *lubb-DUBB* sound. Explain what is happening in the heart to produce this sound. K/U A
6. Cardiac muscle is myogenic, but the nervous system can influence the heart rate. Explain this apparent contradiction. K/U T/I
7. What is the purpose of the Purkinje fibres in the heart? K/U
8. (a) Why is electrocardiography a useful technology in medicine?
   (b) Using a sketch of a normal ECG wave, describe what is happening in each section. K/U T/I C A
9. Use the Internet and other sources to research digital stethoscopes. K/U T/I C
   (a) Write a summary of your research. Be sure to explain how a digital stethoscope is different from a regular stethoscope, and describe the capabilities of a digital stethoscope.
   (b) From the perspective of a doctor, how do you think the digital stethoscope benefits both doctor and patient?

GO TO NELSON SCIENCE

Coronary Artery Disease

11.5

Many diseases and disorders can affect the functioning of the circulatory system. Whatever the nature of the disorder, the fundamental problem is that it interferes with the delivery of oxygen and other substances around the body. The most common circulatory system disorders are those that affect the heart directly, and the most common form of heart disease involves problems with the coronary arteries.

Arteriosclerosis

As you learned in Section 11.3, the elasticity in healthy arteries helps them to effectively circulate blood through the body. Over time, too much pressure in the arteries can result in the hardening and loss of elasticity of the arterial walls. This process is called **arteriosclerosis**, or hardening of the arteries.

One way in which arteries harden involves fatty deposits, called **plaque**, building up on or just underneath the inside walls of arteries. Fat, cholesterol, calcium, and other materials that are normally present in the blood can accumulate inside the arteries to form plaque (**Figure 1**). This hardening of the arteries due to plaque buildup creates a condition known as **atherosclerosis**. Atherosclerosis can occur in any artery of the body. When it occurs in the coronary arteries, it is referred to as **coronary artery disease (CAD)** or coronary heart disease. Next to cancer, CAD is the leading cause of death in Canada.

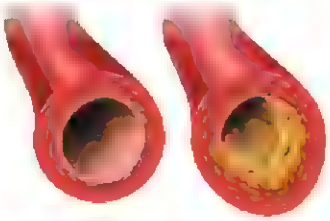


Figure 1 Plaque buildup on and underneath the artery wall. This reduces or blocks the flow of blood.

arteriosclerosis the loss of elasticity and hardening of the arteries that may be caused by a number of factors including hypertension, age, and plaque buildup

plaque deposits of fat, cholesterol, calcium, and other materials on and in the walls of arteries

atherosclerosis the hardening of the arteries due to the buildup of plaque on or inside the walls of the arteries; atherosclerosis is the most common form of arteriosclerosis

coronary artery disease (CAD) the buildup of plaque on or inside the walls of the coronary arteries

Risk Factors for Coronary Artery Disease

The major risk factors that contribute to CAD are high blood pressure, high cholesterol, diabetes, being overweight or obese, smoking, physical inactivity, gender, genetics, and age. Any one of these factors may not be critical in itself, but a combination of factors significantly increases the risk of heart disease. These factors are also interrelated. For example, obesity can increase the chances of developing other risk factors, such as high blood pressure, high blood cholesterol, or diabetes.

One of the major risk factors is high cholesterol. Cholesterol is a fatty substance produced in the liver and carried in the blood to all cells. Cholesterol is an important substance because it is used in building cell membranes and hormones. About 70 % of the cholesterol in the body is produced in the liver; the remaining 30 % comes from foods such as meat, eggs, and dairy products, which contain cholesterol. Cholesterol and other fats do not dissolve in the blood, so they cannot move throughout the body by themselves. Instead, they are transported in the blood by special carriers called lipoproteins. There are two types of lipoprotein—high-density lipoprotein (HDL), commonly referred to as "good cholesterol," and low-density lipoprotein (LDL), commonly referred to as "bad cholesterol." A high level of LDL in the blood contributes to the buildup of plaque on the walls of arteries. HDL seems to have the opposite effect, by carrying cholesterol back to the liver where it is removed from the body.

Symptoms of Coronary Artery Disease

Without diagnostic testing, individuals may not be aware that they have CAD. However, a common symptom is angina. **Angina** is pain most often in the chest area but also in the left shoulder, arm, or neck. Angina may range from a low-level discomfort or tightness to more severe aching or pressure. It is often mistaken for indigestion or heartburn. Angina is caused by reduced blood supply to the cardiac muscles and is often triggered by physical activity that increases the demand for oxygen. Angina is most commonly treated with a drug called nitroglycerin. Nitroglycerin is a vasodilator; it dilates or increases the diameter of the coronary arteries to increase the blood flow to the heart muscles.

angina pain in the chest, left shoulder, arm, or neck caused by insufficient blood supply to the cardiac muscles

Heart Attack: A Consequence of Coronary Artery Disease

myocardial infarction the death of cardiac muscle tissue due to oxygen deprivation; also known as a heart attack

One of the frequent consequences of CAD is a heart attack or myocardial infarction. A **myocardial infarction** is the death of an area of heart muscle tissue due to oxygen deprivation. If the surface of one of the plaques in a coronary artery ruptures, a blood clot will form at the site of the rupture. This blood clot blocks the flow of blood to some of the heart muscle cells. If blood flow is not restored within 20 min to 40 min, those muscle cells begin to die. Cells will continue to die for six to eight hours, so it is extremely important to receive treatment as early as possible. A heart attack may be fatal if a large area of cardiac muscle is affected. A heart attack may also lead to death if the attack interferes with the heart rhythm and the heart stops beating. When this happens, it is referred to as cardiac arrest.

LEARNING TIP

Word Origins

Myo means "muscle," *cardial* means "of the heart," and *infarct* means "plug up or block." Together, "myocardial infarction" means that the supply of blood to the heart muscle is blocked.

Although a heart attack usually occurs suddenly, warning symptoms often occur hours, days, or even weeks before an attack. The most common symptoms are chest pain or pressure and difficulty breathing. Other common symptoms include pain in the arm, back, or jaw; nausea; vomiting; and sweating. There are challenges in predicting a heart attack, and the symptoms are not always the same for everyone. In approximately one quarter of all instances there are no symptoms. Furthermore, some of the common symptoms, such as nausea, heartburn, or stomach cramps, are attributed to indigestion or other digestive system problems rather than circulatory system problems.

Treatment for Coronary Artery Disease

angioplasty a medical procedure that opens up a blocked artery; it is often used to enlarge narrowed openings in coronary arteries

Several options are available to treat heart attacks, depending on the extent and severity of the blocked arteries. These options include lifestyle changes, angioplasty, and bypass surgery.

Three major lifestyle changes are often recommended to prevent or alleviate heart attacks and CAD in general: regular exercise, a healthier diet, and quitting smoking. Regular exercise increases HDL (good cholesterol) in some people, and it helps control other risk factors such as high blood pressure, diabetes, and obesity. Medications may also be used in combination with these lifestyle changes to reduce the buildup of plaque in the arteries.

WEB LINK

To learn more about the causes, symptoms, and treatments of heart attacks,

GO TO NELSON SCIENCE

Angioplasty involves opening up a blocked artery by inflating a small balloon at the point of the blockage. The balloon presses the buildup of plaque against the wall of the artery and widens the opening (**Figure 2(a)**). An expandable mesh tube, called a stent, may be placed at the site of the blockage to ensure that the artery remains open (**Figure 2(b)**). A laser could also be used to vaporize the plaque and open up the artery.

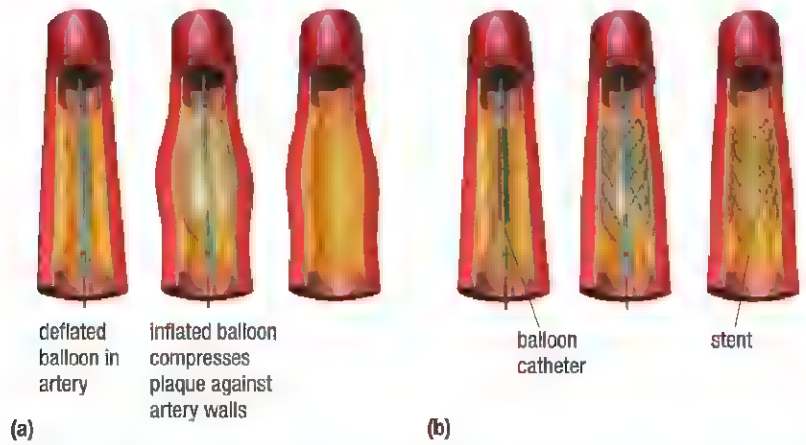


Figure 2 (a) A blocked artery can be opened up using balloon angioplasty. (b) A stent is sometimes used in angioplasty to ensure that the blocked artery remains open at the site of the plaque buildup.

Coronary artery bypass grafting, commonly called **bypass surgery**, is a type of surgery that reroutes, or "bypasses," blood around clogged coronary arteries to improve blood flow and oxygen to the heart muscles. In this procedure, arteries or veins from another part of the body, most commonly a vein from the leg, are grafted to the coronary arteries to bypass a blocked artery (**Figure 3**). This creates an alternate passage for blood to flow around the blockage.

Bypass surgery is usually performed with the heart stopped and is undertaken only in severe cases if other, less invasive treatments, such as angioplasty, are not appropriate. The graft artery can also become blocked if the patient does not take prescribed medications and make appropriate lifestyle changes.

Although bypass surgery is a life-saving procedure, it is not without risks. It involves cutting open the thoracic cavity by cutting through the sternum (breastbone). This is a major surgery and, as with any surgery, there are risks such as bleeding, infections, poor healing, and other complications.

bypass surgery a surgical procedure in which arteries are grafted to blocked (or narrowed) coronary arteries in order to reroute blood flow and oxygen to the heart

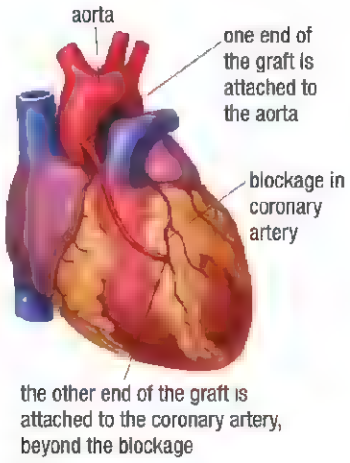


Figure 3 A coronary bypass redirects blood around the blockage in the coronary artery so that the heart muscles receive an adequate blood supply.

11.5 Summary

- Atherosclerosis is the condition that results from the buildup of plaque in the arteries. The buildup of plaque reduces blood flow, and a rupture of the plaque can create a clot that completely blocks the flow of blood.
- Atherosclerosis in the coronary arteries is referred to as CAD.
- A common symptom of CAD is angina, or pain in the chest area, caused by insufficient blood supply to the heart muscles.
- A myocardial infarction, or heart attack, can occur when the blood supply to the heart muscles is blocked. A heart attack results in the death of cardiac muscle tissue due to oxygen deprivation.
- When blockages occur in the coronary arteries, procedures such as angioplasty and bypass surgery can restore blood flow to muscles of the heart.
- Lifestyle changes such as appropriate diet, increased physical activity, and stopping smoking can reduce the risk of or alleviate heart disease.

11.5 Questions

1. Describe the condition known as atherosclerosis. What factors contribute to the development of this condition? K/U
2. (a) Explain how cholesterol is an important factor in coronary artery disease (CAD).
   (b) Why is LDL cholesterol referred to as "bad cholesterol" and HDL cholesterol as "good cholesterol"? K/U A
3. Use the Internet and other sources to find out how smoking, blood pressure, diabetes, and genetics all contribute to CAD. Write a brief summary of your findings.
4. A 50-year-old male who is not overweight and has normal blood cholesterol levels suffers a heart attack. Propose a possible explanation. K/U T/I A
5. Explain how CAD can lead to a heart attack. K/U A
6. Use the Internet and other sources to find out the symptoms of a heart attack and the recommended actions that should be taken. Prepare a brochure with essential information to distribute to family and friends.
7. Suppose a friend is overweight and inactive, and a recent blood test revealed high levels of LDL cholesterol. Being sensitive to your friend's feelings, write a letter discussing the risks associated with these factors and recommend lifestyle changes that might reduce the risks. K/U C A

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11.6

Imaging: Looking through the Body

The structure of the mammalian body has evolved to protect the vital organs of the digestive, respiratory, and circulatory systems. The heart is located in the core of the body, protected by the rib cage and the pericardium and supported by connective tissues. This protection makes the diagnosis and treatment of disorders of the circulatory system challenging.

Invasive and Non-invasive Tests

The most direct way of observing the heart and other parts of the circulatory system is to actually go inside the body, an approach referred to as invasive. The most invasive and traumatic approach is surgery. Opening up the body to observe an organ is usually the last resort and is used only in extreme circumstances. Since the heart cannot easily be observed directly, science and technology have devised indirect methods of seeing inside the body. These methods are either much less invasive than surgery or are completely non-invasive. While invasive procedures can be used for diagnosis and treatment, non-invasive tests are usually done for diagnostic purposes only—that is, to identify a problem or to confirm a suspected problem.

WEB LINK

To learn more about the technology used to diagnose cardiovascular disorders and diseases,

GO TO NELSON SCIENCE

Cardiac Catheterization

cardiac catheterization the insertion of a long thin tube called a catheter into the heart through an artery, usually the femoral or brachial artery

Cardiac catheterization, also known as cardiac angiography, is the most common procedure for investigating coronary artery disease. It involves threading a long flexible tube, called a catheter, into the heart through a blood vessel. It is far less invasive than surgery because it requires only a small incision to allow access to a large blood vessel. Often the catheter is inserted through the femoral artery, though alternatively, it can be inserted through the brachial artery (**Figure 1(a)**). The catheter is advanced to the coronary arteries. A special contrast material, often called contrast dye, is then injected into the bloodstream. The contrast dye is opaque to X-rays. When an **angiogram** (a two-dimensional X-ray) is taken, the contrast dye shows the circulation of blood through the coronary arteries. Decreased or lack of blood flow in an artery indicates that the artery is significantly narrowed or blocked (**Figure 1(b)**).

angiogram an X-ray image showing the outline of blood vessels through the use of an injected dye

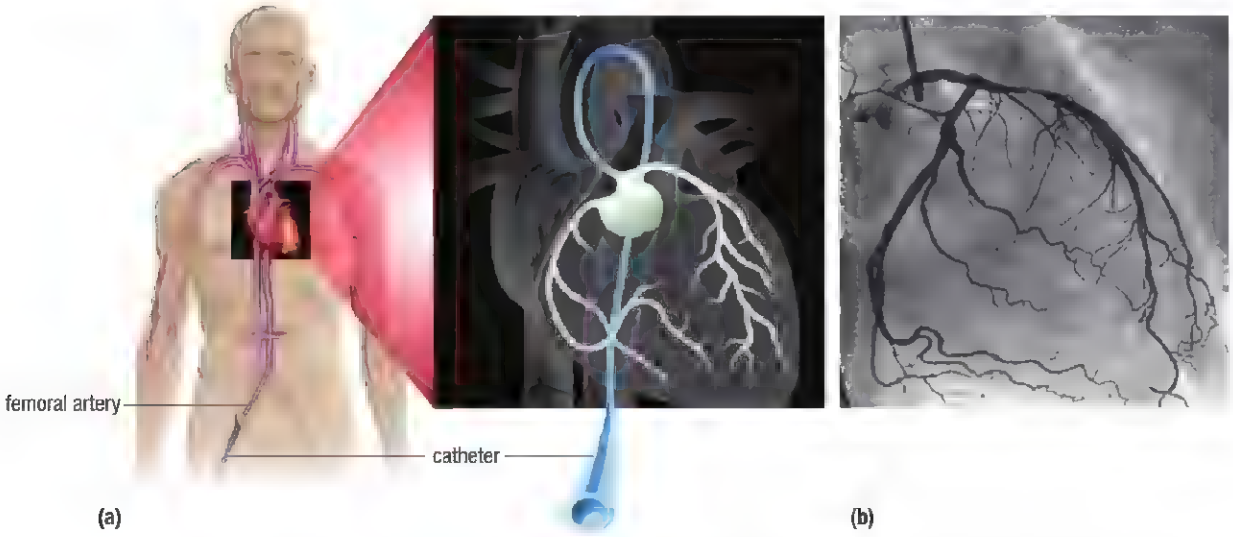


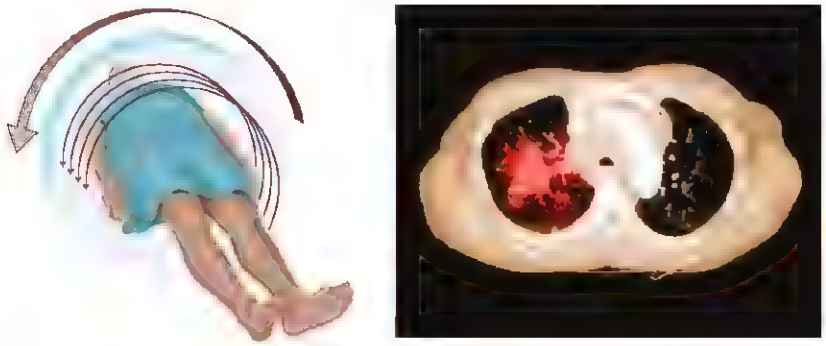
Figure 1 (a) A catheter is inserted through the femoral artery, into the aorta, and into the coronary arteries. (b) The angiogram shows blood flowing through the coronary arteries. A significant narrowing in one of the coronary arteries indicates reduced blood flow to that area. Can you identify where the blockage is?

CT and PET Scans

Diagnostic tools are now available that produce much more detailed images than a regular X-ray machine. Despite this, cardiac catheterization and X-rays are still the most commonly used standard diagnostic tool because they are more widely accessible.

One of the newer tools is the **computerized tomography (CT) scan**. Tomography is the process of creating a two-dimensional (2-D) image of a cross-section through a three-dimensional (3-D) object. Computerized tomography involves using a computer to manipulate the images produced during the scan. A CT scan produces a series of X-ray cross-sectional views or slices of the body (**Figure 2**). The patient lies on a table that slides through the X-ray machine as the machine rotates around the body.

computerized tomography (CT) scan an X-ray imaging technology that produces cross-sectional images of a three-dimensional object



(a) (b)

Figure 2 (a) The CT scanner rotates around the body, (b) creating X-ray images of cross-sectional slices through the body.

The CT scan was invented in 1972 by British engineer Godfrey Hounsfield. The original CT scanner produced a single slice image per rotation and required several hours to obtain the image. CT was a major breakthrough at the time because it could capture images of soft tissue. Improvements in the technology have progressed from the single slice to 2-, 4-, 16-, 64-, 128-, and, most recently, 256-slice scanners. These 256-slice scanners produce 256 images per rotation of the machine. The rotation speed is greater than 3 rotations per second, allowing more than 750 images per second! This speed produces clear and detailed images in only a few seconds. In fact the whole body can be scanned in under 10 s. The images produced are also of higher quality, because the patient can hold his or her breath for the duration of the scan, thereby reducing any body movement that might affect the images.

The cross-sectional images obtained during the scan can then be combined using special computer software to produce a 3-D image (**Figure 3**). One of the disadvantages of this technology is that patients receive higher doses of radiation from the multi-slice CT scan than from a single-slice CT or regular X-ray.

Figure 3 This image of the heart and coronary arteries was produced by a 256-slice CT scanner.

CT scans can be used to produce a 3-D angiogram to show the outline of blood vessels. Coronary CT angiography (CTA) is a quicker and less invasive procedure than coronary angiography because it is not necessary to insert a catheter into the coronary arteries. A contrast dye is injected into the bloodstream through a blood vessel in the arm to improve the clarity of the images.

The **positron emission tomography (PET) scan** is similar to the CT scan, except that it uses gamma rays instead of X-rays. A radioactive tracer is either injected into the bloodstream if the circulatory system is being scanned, or swallowed if the digestive system is being scanned. This radioactive material emits gamma rays that are detected by a gamma camera in the scanner. The camera converts the emitted gamma rays into electrical signals that are interpreted by a computer to produce images. Like X-rays and CT scans, this technology exposes the patient to radioactive materials. Overexposure to radiation can damage cells and increase the risk of developing cancer.

positron emission tomography (PET) scan an imaging technology that produces cross-sectional images from gamma rays emitted by a radioactive tracer injected into body tissues

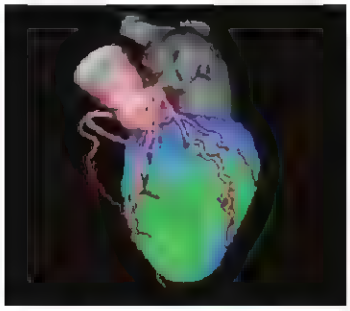


Figure 4 This image of the heart and coronary arteries was produced by combining images from CT and PET scans, a process called image fusion.

Modern machines combine both CT and PET scanners so that both scans can be performed during the same procedure. The images from both scans are combined to produce much clearer images than either scan alone (**Figure 4**). Such images enable a more accurate diagnosis and better decisions on follow-up treatment.

CARDIAC CALCIUM SCORE

Calcium is among the materials in plaque that cause atherosclerosis. A CT scan is used to detect calcium accumulation in the coronary arteries. Interpretation of the images produces a cardiac calcium score that indicates the degree of buildup and the extent of atherosclerosis. A score of zero indicates no evidence of calcification in the coronary arteries. A score between 100 and 400 shows moderate evidence of coronary artery disease. A score over 400 constitutes extensive evidence of coronary artery disease.

The absence of calcium deposits in the coronary arteries does not mean that there are no problems. Soft plaque buildup may not be detected during such a scan but is just as dangerous as hard plaques in reducing or blocking blood flow to the heart muscles.

Cardiac MRI Scan

magnetic resonance imaging (MRI) scan an imaging technology that produces images by using a magnetic field to change the orientation of hydrogen atoms in tissues

The least invasive and maybe safest test for diagnosing coronary artery disease is the **magnetic resonance imaging (MRI) scan**. An MRI scan uses radio waves and a large magnet to produce still and video images. A large circular electromagnet surrounds the patient (**Figure 5**). The magnetic field surrounding this magnet changes the orientation of the hydrogen atoms in the tissues. This produces a change in the energy level of the atoms, which is detected and translated by a computer into an image.

Figure 5 During an MRI, the patient lies on a bed that slides into the scanner. MRI scans usually take 20 min to 60 min.

CAREER **LINK**

Medical Imaging Technologist
Would you like a career as a medical imaging technologist? To learn more about this career,

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MRI scans are considered safer than X-rays, CT scans, or PET scans because they do not require exposure to radiation. MRI technology has other unique advantages, too. For example, MRI scans can produce images of the heart throughout the cardiac cycle. When used to scan the heart or other part of the circulatory system, the MRI scan is often referred to as a cardiovascular MRI or CMR scan. Using a CMR scan, cardiologists can identify any problems with the contraction of the ventricles or blood flow patterns in the heart. CMR scans can also identify regions of heart muscle that are not receiving proper blood flow or that have been damaged by a heart attack.

Despite all the advantages of this technology, an area of concern is its availability. MRI machines are very expensive to purchase and operate, and the demand for MRI scans exceeds the capacity. Depending on where you live, there may be a significant wait time. Travel to a larger centre may also be involved in order to obtain the service.

Research This

Doppler Ultrasound

Skills: Researching, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1, A5.1

Medical sonography, or ultrasonography, is a common imaging technology that is used in the diagnosis of diseases and disorders, and in monitoring fetal development during pregnancy. A special type of ultrasound imaging, called Doppler ultrasound, is used to evaluate blood flow.

1. Use the Internet and other sources to research the use of Doppler ultrasound in medicine. Use the following topics to guide your research:
   (a) how ultrasound imaging technology works
   (b) how Doppler ultrasound imaging is used for diagnosing medical problems related to the circulatory system
   (c) benefits and risks of ultrasound imaging technology
   (d) cost of ultrasound imaging compared with other imaging technologies

A. Using a simple diagram, explain how Doppler ultrasound works. K/U C

B. Why is ultrasound technology considered safer than many other imaging technologies? K/U A

C. What are the most common reasons for doing Doppler ultrasound? K/U A

D. Explain why Doppler ultrasound is particularly suited to diagnosing blood flow problems. K/U A

E. Evaluate the importance of Doppler ultrasound imaging technology in diagnosing medical problems related to the circulatory system. T/I A

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11.6 Summary

- Tests that require direct observation of the inside of the body are called invasive. Non-invasive tests do not require physical entry into the body.
- Cardiac catheterization involves threading a catheter through the femoral or brachial artery into the aorta and into the coronary arteries. A contrast dye is injected so that the blood vessels will show up on an angiogram.
- Computerized tomography, or CT, produces a 2-D cross-sectional image of a 3-D object. A series of these images can then be compiled into a 3-D image.
- Positron emission tomography, or PET, produces images by capturing gamma rays that are emitted from a radioactive tracer injected into the body.
- A calcium cardiac score indicates the extent of coronary artery disease based on the amount of calcium in the plaque buildup in the coronary arteries. A cardiac CT scan reveals the amount of calcium in the arteries.
- Magnetic resonance imaging, or MRI, produces images by sending out radio waves that change the energy levels of hydrogen atoms in body tissues. MRI does not require exposure to any radioactive material.

11.6 Questions

1. Why is cardiac catheterization considered an invasive procedure? K/U
2. (a) Briefly explain the difference between CT and PET.
   (b) What is the advantage of the new imaging technologies over old technology such as X-rays? K/U A
3. (a) Why is MRI considered a safer imaging technology than CT or PET?
   (b) What other advantage might MRI have over other imaging technologies? K/U T/I A
4. Describe the medical and social benefits and risks of new technologies such as CT, PET, and MRI. K/U A
5. The percentage of the provincial budget required to support the healthcare system is growing, partly because of very expensive technologies such as CT, PET, and MRI. Do you think the benefits of these technologies justify the costs? Explain your answer. K/U T/I A
6. A concern related to our healthcare system is the wait time for medical tests and procedures. Use the Internet and local sources to research the wait times for various imaging procedures in your area. Write a brief report of your findings. Do you think the wait times are reasonable? Explain your answer. T/I C A

GO TO NELSON SCIENCE

11.7 Explore Applications of Technology in Diabetes Management

SKILLS MENU

- Researching
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating
- Identifying Alternatives

Technology for Insulin Delivery

Body cells must receive a fairly continuous supply of glucose in order to function properly. When you eat, the process of digestion provides glucose to the bloodstream. Because we are not continuously eating, there is a regulatory mechanism that ensures that the blood glucose level remains within an acceptable range. The regulation of the blood glucose level is controlled by groups of cells in the pancreas called islets of Langerhans.

When the blood glucose level rises, the islets of Langerhans produce a hormone called insulin. Insulin binds to special receptors in the surface of body cells and allows glucose to enter the cells through the cell membrane. The glucose is stored in the body cells temporarily until it is needed as an energy supply for various cellular functions. As glucose continues to enter the cells, the level of glucose in the blood drops and the islets stop making insulin. As the blood glucose level drops, the islets of Langerhans start producing another hormone, called glucagon. Glucagon stimulates the liver, muscles cells, and fat cells to break down glycogen and release glucose into the bloodstream. This raises the blood glucose level.

These two hormones, insulin and glucagon, maintain a balance of the blood glucose level (**Figure 1**). Although the blood glucose level is balanced, it is not constant. It varies throughout the day, rising after each meal. As the available glucose is used or stored, the level decreases again to the normal range. The blood glucose level is lowest in the morning before breakfast.

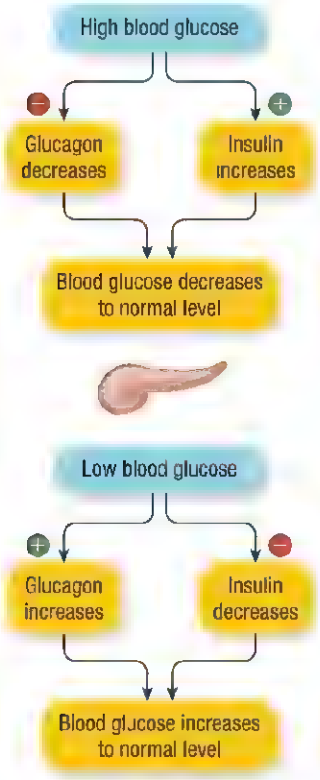

Figure 1 The pancreas secretes glucagon and insulin. These hormones maintain a balance of the blood glucose level.

Diabetes is a disorder that affects the ability of the body to use glucose for energy. Diabetes is characterized by high levels of glucose in the blood. This condition can occur for two reasons: the pancreas may produce no insulin or insufficient insulin, or the body cells are unresponsive to insulin and glucose does not enter the cells. Excess glucose in the blood is filtered by the kidneys and excreted in the urine.

Type 1 diabetes occurs when the pancreas cannot produce insulin. This type of diabetes develops in younger children and adolescents and accounts for about 10 % of cases of diabetes. Type 1 diabetes is an autoimmune disease in which the immune system attacks the cells of the pancreas that produce insulin. The reason for this is not understood.

Type 2 diabetes usually develops after age 30 and occurs when the pancreas produces insufficient insulin or when the insulin receptors on the cell surface do not function properly so that the insulin produced is not effectively used by the cells. The exact cause of type 2 diabetes is not known. Research indicates that lifestyle factors that cause obesity, such as physical inactivity and a high-calorie diet, significantly contribute to the incidence of this type of diabetes. Researchers also believe that a genetic link and family history is likely to be a significant factor.

Diabetes is associated with atherosclerosis and blood vessel damage. High blood sugar levels can damage many body tissues, including blood vessels. Diabetes significantly increases the risk of developing coronary artery disease and the likelihood of having a heart attack.

Diabetes cannot be cured presently, but it can be successfully managed and diabetics can lead a fairly normal life. Management of the disease has three components: diet, exercise, and medications. Individuals with type 1 diabetes require daily administrations of insulin. Their blood glucose level must be checked regularly and the amount of insulin adjusted according to the level. Diabetics must also follow a special diet and exercise regularly. Type 2 diabetes can usually be managed successfully through diet and exercise. Individuals with type 2 diabetes also need to monitor their blood glucose level at least daily. If their blood glucose level cannot be controlled through diet and exercise, they may need to take medications or insulin.

The Application

Since the discovery of insulin, researchers have attempted to find the best way of managing diabetes through the administration of insulin. This aspect of management has two components: monitoring the blood sugar levels and delivering the insulin. For many years the standard methods were to prick the finger and test the blood with a strip, and to administer insulin by injection using a hypodermic needle. This requires continuous monitoring of blood sugar levels so that the diabetic knows if and when to administer insulin and how much. These methods are somewhat painful, often inconvenient, and challenging to maintain.

Although the goal is to find a cure for diabetes, the need for more appropriate methods of monitoring blood sugar and administering insulin has led to the development of new technologies. They include insulin pens, insulin pumps, inhalation therapy, and an artificial pancreas. These technologies provide better management for the disease and a better quality of life for diabetics and their families.

Your Goal

You will prepare a technology update that summarizes the available and upcoming technologies for the management of diabetes. The purpose of this update will be to promote awareness among diabetics, their families, and the general public.

Research

SKILLS HANDBOOK A2.1, A5.1

Use the Internet and other sources to research available and emerging technologies that are used to monitor blood glucose levels and administer insulin. Consider the following questions to help guide your research:

- What technologies are currently available? How do these technologies work?
- What are the most commonly used technologies?
- What new technologies are under development?
- What scientific or technological principles are these new technologies based on?
- What are the advantages and risks associated with the new technologies?
- Are the new technologies accessible to all diabetics? (Consider factors such as cost, ease of use, convenience, and so on.)

WEB LINK

To begin your research on this topic,

GO TO NELSON SCIENCE

Summarize

Prepare an outline for your technology update. Use this outline as the basis for selecting information from your research.

Communicate

SKILLS HANDBOOK A2.1

How will you convey the important information to diabetics and others? Choose the format for your technology update that you think will be most effective. Possible formats include a brochure, booklet, video, slideshow, oral presentation, or display. Remember to consider your intended audience when selecting the format.

Plan for Action

In addition to monitoring blood sugar levels and the administration of insulin, the management of diabetes usually involves changes in diet and activity level. Can everyone benefit by following the recommended diet and exercise for diabetics?

- Use the Internet and other sources to determine how diet and exercise can be used as part of an effective diabetes management plan.
- Prepare a list of foods and exercises that are effective in controlling blood sugar levels for diabetics.
- Make a personal plan for diet and exercise as if you were a diabetic. Follow this plan for a week. Keep a daily record of your diet and physical activities, including observations of how you feel physically and emotionally.

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CHAPTER 11 Investigations

Investigation 11.1.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Fetal Pig Dissection

The body systems of pigs are structurally very similar to human body systems. Dissecting a pig gives you a good idea of what the digestive, respiratory, and circulatory systems of humans look like. The fetal pig will be used in this investigation because its size is manageable in the classroom.

At the end of the dissection, you will have viewed all of the major structures of the digestive, respiratory, and circulatory systems. However, the systems will not be observed in sequence. You will be instructed to view the structures as they become visible during the dissection. Your teacher may use the opportunity to have you examine parts of other body systems, such as the reproductive and nervous systems.

Refer to the appropriate sections of Chapters 9, 10, and 11 to refresh your memory about the structures of the three systems and their functions.

Purpose

To dissect a fetal pig and examine the structures and arrangements of the digestive, respiratory, and circulatory systems

Equipment and Materials

SKILLS HANDBOOK A1.1

- eye protection
- apron
- dissecting gloves
- preserved fetal pig
- dissection tray
- string
- scissors
- dissecting pins
- scalpel
- probe
- forceps
- hand lens
- ruler

Wear your eye protection, gloves, and apron at all times during the dissection and clean up.

If any of the preserving chemical contacts your clothing or skin, remove clothing immediately and thoroughly rinse the skin with water. If the preservative splashes into your eyes, rinse thoroughly for 15 min.

To avoid inhaling the preservative, work in a well-ventilated area and do not place your face directly over the specimen.

Procedure

SKILLS HANDBOOK A1.2, A2.4, A3.1, A3.2

The following anatomical terms will help you orient the specimen and determine the position of a structure in relation to other structures. Refer to **Figure 1** and **Figure 2** (next page) as you review the terms.

- **Anterior** means the head end or toward the head end. If structure A is anterior to structure B, then it is closer to the head.
- **Posterior** means the tail end or toward the tail end. If structure A is posterior to structure B, then it is closer to the tail end. Posterior is opposite to anterior.
- **Dorsal** means the back side or toward the back.
- **Ventral** means the belly side or toward the belly. Ventral is the opposite of dorsal.
- **Lateral** means to the side. This refers to positions left or right of a central anterior–posterior line when viewing the organism from the back (dorsal side). Left and right refer to the sides of the organism, not the observer.
- **Medial** means in the middle.
- **Proximal** means away from the extremities toward the body.
- **Distal** means away from the body toward the extremities.

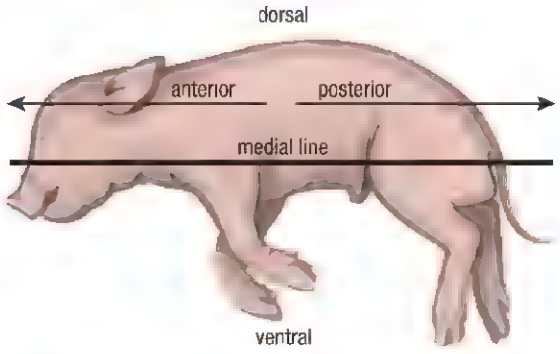

Figure 1 Anatomical terms shown on lateral view of fetal pig

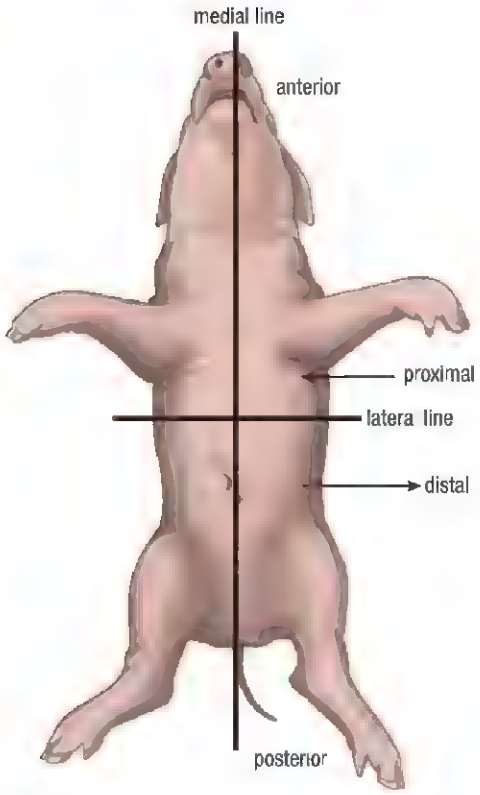

Figure 2 Anatomical terms shown on ventral view of fetal pig

Part A: Preparation for Dissection

If, at any time, you feel uncomfortable during the dissection, inform your teacher and follow his or her directions.

1. Place the pig on its back (dorsal surface) on the dissecting tray.
2. Tie a string to one of the forelegs of the pig, wrap the string around the bottom of the tray, and tie it to the other foreleg. Repeat with the hind legs (**Figure 3**).

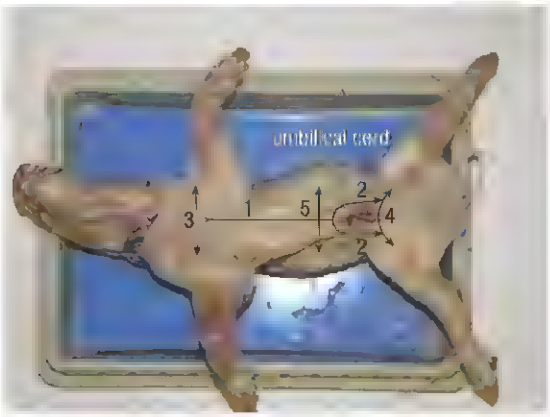

Figure 3 The ventral view of a feta pig

When using the scalpel or scissors, always cut away from yourself and others.

3. Use scissors to make incisions in the sequence indicated in Figure 3. Start by cutting above and to the sides of the umbilical cord. Remember to make notes and labelled biological drawings as you proceed.
   - Incision 1 is a medial incision from the umbilical cord toward the head.
   - Incision 2 involves two incisions. Cut from the anterior side of the umbilical cord down each side of the umbilical cord toward the tail end (posterior).
   - Incision 3 is a lateral incision at the base of the neck to the shoulders. Start from the medial incision and cut toward each side.
   - Incision 4 is a lateral incision at the base of the abdomen toward each hind leg. Again, start from the medial incision and cut toward each side.
   - Incision 5 is a lateral incision immediately anterior to the umbilical cord. It is parallel to the diaphragm, which separates the abdominal cavity from the thoracic cavity. Start from the medial incision and cut toward each side.
4. Pull back the flaps of skin and use pins to hold them back. Use the probe to open the connective tissue that holds the internal organs to the lining of the body cavity.

Part B: The Oral Cavity

5. Make an incision on each corner of the mouth, extending back toward the neck. Pull the lower jaw and tongue down toward the chest to expose the structures in the mouth and throat (**Figure 4**).

Figure 4 The oral cavity of a fetal pig

6. Identify the epiglottis and the entryways to the esophagus and the trachea.
7. Make an incision from the chin along the neck to the previous incisions. Use the scalpel and probe to separate muscle and other tissues in the neck. Identify the esophagus and trachea, and follow these structures until they disappear into the thoracic cavity. Identify the larynx (it is an enlarged area in the trachea).

Part C: The Abdominal Cavity

8. Locate the liver, which lies immediately posterior to the diaphragm. Examine the liver and note the number of sections, or lobes (**Figure 5**).

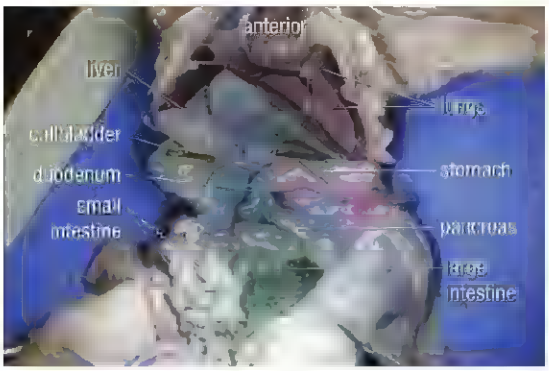

Figure 5 The abdominal cavity of a fetal pig

9. Use the probe to move the lobes of the liver and locate the gall bladder. Note the location of the gall bladder using appropriate anatomical terms from the introduction to Part A.
10. Follow the thin bile duct leading from the gall bladder to where it empties into the small intestine.
11. Lift the liver and identify the J-shaped stomach. Note where the esophagus joins the stomach and where the stomach joins the duodenum of the small intestine.
12. Where the stomach meets the small intestine, use the probe and forceps to separate the thin connective tissue that holds the organs in place in the abdominal cavity. Straighten the first section of the small intestine and identify the pancreas. Describe the appearance of the pancreas. Note the blood vessels that carry digested nutrients from the intestine to the liver.
13. The spleen is a long organ located on the outside curved part of the stomach. Locate the spleen and describe its appearance.
14. Remove the stomach by cutting across the esophagus at the anterior end (closer to the head) and across the small intestine at the posterior end (closer to the tail). Make a medial incision along the length of the stomach and open it. Rinse the inside of the stomach with slow-running tap water. Observe the inner lining of the stomach with a hand lens, and describe the inner lining.
15. Separate the connective tissue and straighten the intestines. Measure the lengths of the small and large intestines with a ruler.
16. Lift the liver and intestines and observe the blood vessels at the dorsal part of the abdominal cavity. These blood vessels run from the heart to the organs of the posterior part of the body and the hind legs.
17. While you are exploring the blood vessels, identify the two umbilical arteries and one large umbilical vein. Trace the origin of these blood vessels.

Part D: The Thoracic Cavity

18. Use scissors to cut through the ribs on each side of the thoracic cavity. Remove the ventral (belly side) section of the rib cage to expose the organs in the thoracic cavity.
19. Use the scalpel to separate and remove the diaphragm from the body wall.
20. Locate the heart. Using forceps and the probe, remove the pericardium (the thin connective tissue) from the outer surface of the heart. Observe the structure of the heart and the major blood vessels leading to and from the heart (**Figure 6**). Note also the coronary arteries that supply blood to the cardiac muscles.

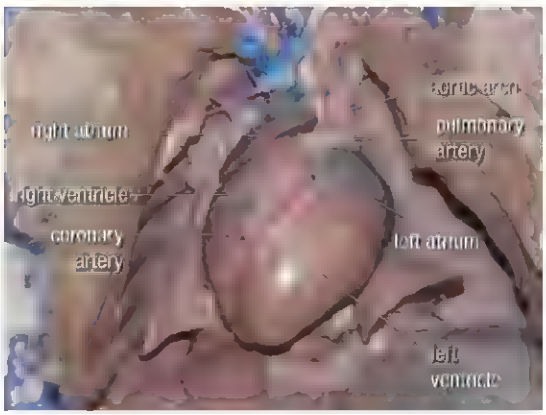

Figure 6 The heart of a fetal pig

21. Using the probe and forceps, tease away the connective tissue from around the major blood vessels leading to and from the heart. Remove the heart by cutting the blood vessels about 2 cm from the heart.
22. Examine the heart and identify the following structures: right atrium, left atrium, right ventricle, left ventricle, coronary arteries, aorta, pulmonary artery, pulmonary vein, superior vena cava, and inferior vena cava. (Remember, right and left refer to the pig's right and left, not yours.)
23. Make a diagonal incision through the heart and expose the chambers of the heart. Starting at the right atrium, follow the path of blood through the chambers and major blood vessels attached to the heart.
24. Find the trachea and the bronchi leading into the lungs (**Figure 7**, next page). Use your fingers to examine the trachea. Describe how the trachea feels to the touch.

Figure 7 The thoracic cavity of a fetal pig

25. Locate the lungs, which lie underneath and to either side of the heart. Identify the lobes of the lungs. Describe the look and feel of the lungs.
26. After completing the dissection, dispose of the specimen and other materials as instructed by your teacher. Clean your work area and equipment and return the equipment to its storage area. Wash your hands thoroughly with soap and water after you have finished the dissection.

Analyze and Evaluate

(a) Relying on the notes you made during your dissection, draw simple labelled diagrams of the digestive, respiratory, and circulatory systems of the fetal pig. K/U C A

(b) From your examination of the mouth and throat, explain the function of the epiglottis. K/U T/I C A

(c) What is the ratio of the length of the small intestine to the length of the large intestine? How does this compare with the ratio of the lengths of the intestines in humans? T/I A

(d) What did you notice about the structure of the trachea? What is the function of the special design of the trachea? K/U T/I

(e) What was your description in Step 25 of how the lungs felt to the touch? Why do you think they feel this way? T/I A

(f) Which chamber of the heart was most muscular? Explain why. T/I A

(g) How could you tell the arteries from the veins in the circulatory system? T/I A

(h) What did you find during your dissection that was
  (i) most interesting?
  (ii) most surprising?
  (iii) most disturbing? T/I

(i) Did you experience any difficulty identifying the major organs and tissues? Explain why or why not. What could have been done to avoid any difficulty you experienced? T/I A

Apply and Extend

(j) Write a report that includes a graphic organizer outlining the similarities and differences between the digestive, respiratory, and circulatory systems of a pig and those of a human. K/U T/I C A

(k) Do you think that the fetal pig is a good model to use in training future doctors? Why or why not? T/I A

(l) Xenotransplantation is the transplantation of cells, tissues, or organs from one species to another. Pig cells, tissues, and organs are a potential source for transplantation to humans.

Use the Internet and other sources to research the use of pig cells, tissues, and organs as human transplants. What types of cells, tissues, and organs are used? What are the problems with such transplants? How do you feel about using pig or other animal cells, tissues, and organs for transplantation to humans? T/I C A

(m) Use the Internet and other sources to research the use of actual organisms (living or dead) as models in medical training. Write a brief report of your findings. T/I C A

GO TO NELSON SCIENCE

Investigation 11.3.1 CONTROLLED EXPERIMENT

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

The Effect of Exercise on Heart Rate and Blood Pressure

Exercise requires energy. Energy is provided through cellular respiration. In the process of cellular respiration, oxygen is used to obtain energy from glucose. The overall reaction for cellular respiration is represented by the equation

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

glucose + oxygen → carbon dioxide + water + energy

As the demand for energy increases, the demand for fuel (glucose) and oxygen also increases. How do these increasing demands affect the circulatory system—in particular, heart rate and blood pressure?

Testable Question

How does exercise affect heart rate and blood pressure?

Hypothesis/Prediction

SKILLS HANDBOOK A2.2

Discuss the testable question with your group. Make two predictions and propose a hypothesis to explain each prediction.

Variables

Identify the independent, dependent, and controlled variables in this investigation.

Experimental Design

Design a controlled experiment to test your predictions and hypotheses. Write a brief summary of the overall design of your experiment.

Equipment and Materials

SKILLS HANDBOOK A1.2

Make a list of all the equipment and materials you will need to carry out your experiment. When selecting the equipment and materials, consider the following criteria:

- availability
- accessibility
- ease of operation
- accuracy
- safety
- cost

Procedure

SKILLS HANDBOOK A1.2, A2.2, A2.6

Inform your teacher of any medical condition(s) that might limit your participation in this investigation.

1. Write a detailed step-by-step procedure for carrying out the experiment. This should include safety precautions and an appropriate table in which to record your observations.
2. Submit your predictions, hypotheses, variables, experimental design, equipment and materials list, and procedure to your teacher for approval.
3. Carry out the experiment.
4. Write a lab report that summarizes your findings. Be sure to identify the independent, dependent, and controlled variables.

Analyze and Evaluate

(a) What variables were measured, recorded, and/or manipulated in this investigation? What type of relationship was being tested? T/I A

(b) Evaluate the evidence you gathered in this experiment. Do you think the evidence was of sufficient quantity and quality to confidently answer the testable question? Explain your answer. T/I A

(c) Identify any potential sources of error in your observations. Do you think these errors affected the validity of your conclusions? Explain. T/I A

(d) If you were to repeat this experiment, how would you change your design or procedure to improve the investigation? T/I A

Apply and Extend

(e) Is the amount of change in heart rate during exercise an indicator of physical fitness? Propose a hypothesis based on this question and design an experiment to test it. T/I A

(f) Do your observations show a relationship between heart rate and blood pressure? If so, describe it. T/I A

(g) Use the Internet and other sources to research the factors that affect blood pressure. Write a brief report to present your findings. T/I C A

GO TO NELSON SCIENCE

Investigation 11.4.1 OBSERVATIONAL STUDY

SKILLS MENU

• Questioning	• Planning	• Observing
• Researching	• Controlling Variables	• Analyzing
• Hypothesizing		• Evaluating
• Predicting	• Performing	• Communicating

Analyzing and Interpreting ECGs

The strength and duration of the electrical signals of the heart can be detected and measured using an electrocardiograph (ECG). If there are physiological problems with the heart, these signals are disrupted and produce a different pattern on the electrocardiogram than a normal heartbeat would produce. The abnormal patterns can be interpreted to diagnose a variety of problems such as arrhythmias (abnormal rhythms), abnormal activation sequences, muscle damage, and valve problems.

Remember, the purpose of this investigation is to help you understand how the ECG is used as a tool to diagnose heart problems. It is not intended to train you to interpret an ECG. Interpretation of ECGs is a very complex and difficult skill that should be done only by trained and qualified specialists.

Purpose

To examine abnormal ECGs and use this information to propose possible diagnoses for other abnormal ECGs

Equipment and Materials

- ECGs of normal and abnormal heart rhythms

Procedure

SKILLS HANDBOOK A2.4

Part A: Analyzing Normal ECGs

1. Carefully review Section 11.4 to ensure that you understand the cardiac cycle, how it is observed using an electrocardiograph, and the information about the cardiac cycle that is represented on an ECG.
2. Use the ECG of a normal heart rhythm to calculate the heart rate. The following guidelines will help:
   - Determine a starting point, such as a P wave or a QRS complex, and mark the beginning time.
   - Count off 6 to 10 cardiac cycles and mark the end time on the same point of the wave as the starting point. For example, if your starting point is a P wave, your end point should also be a P wave.
   - Determine the time interval between the starting time and the end time for the selected cycles. Each vertical line represents 0.2 s.
   - Use the following formula to calculate the heart rate in beats per minute.

$$\text{Heart rate (bpm)} = \frac{\text{no. of cycles selected}}{\text{elapsed time (s)}} \times \frac{60\text{ s}}{1\text{ min}}$$

Part B: Analyzing Abnormal ECGs

3. Your teacher will provide a number of abnormal ECGs that indicate the abnormal condition they represent.
4. Compare each of the abnormal ECGs with a normal ECG. Use the letters to label the various parts of the cardiac cycle and the wave intervals. Identify and describe how the abnormal pattern differs from the normal pattern.
5. Your teacher will then provide you with three undiagnosed ECGs. Using your observations from Step 4, propose a possible diagnosis for each of the undiagnosed ECGs.

Analyze and Evaluate

(a) What was the heart rate shown in the normal ECG tracing? Show your calculations. T/I C

(b) Are all the normal cardiac cycle intervals exactly the same? Explain why using more cycles over a longer period of time is more appropriate than a single cycle. T/I A

(c) Explain the characteristics of each of the undiagnosed ECGs that led to your diagnoses. T/I A

(d) Heartbeats among individuals differ in both pattern and strength. How might this make it more difficult to interpret an ECG? T/I A

(e) Did you experience difficulty in identifying the conditions in the undiagnosed ECGs? If so, explain why. T/I

Apply and Extend

(f) Describe in general terms what you think the ECG of an elite athlete would look like. How might this differ from the ECG of an inactive person? T/I A

(g) A complete ECG produces tracings from 10 electrodes that are connected to various points on the body. The tracings you have seen in this investigation come from only one of these leads. Use the Internet and other sources to learn about the 10-lead ECG and what each of the leads monitors. Write a brief report to summarize your findings. T/I A

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CHAPTER 11 SUMMARY

Summary Questions

1. Use a concept map to summarize the main ideas of this chapter. Write words or short phrases on the lines joining the items in your concept map to explain the connections between them. Use your concept map to prepare a Grade 8 lesson about the human circulatory system.
2. Return to the Starting Points questions at the beginning of the chapter, on page 476. Answer these questions using what you have learned in this chapter. Compare your answers with those that you gave at the beginning of the chapter. How has your understanding changed? What new knowledge and skills do you have?

Vocabulary

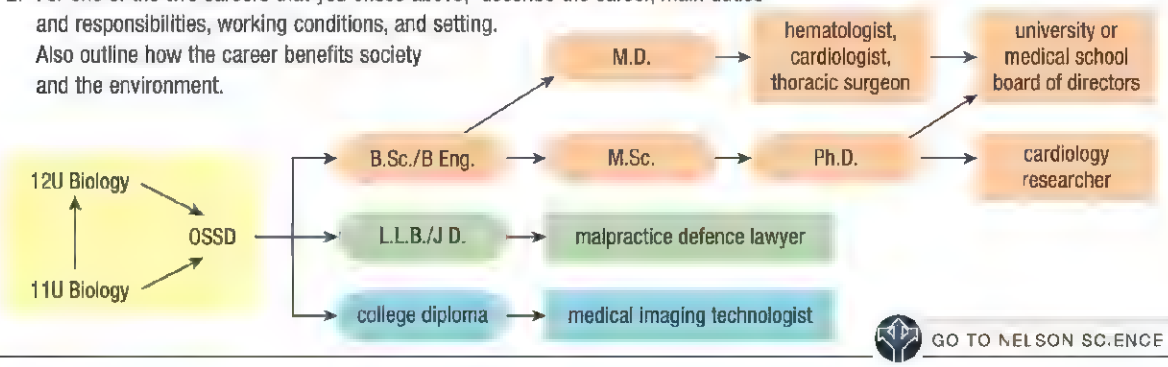
hemolymph (p. 479)
atrium (p. 480)
ventricle (p. 480)
septum (p. 480)
pulmonary circuit (p. 481)
systemic circuit (p. 481)
serum (p. 482)
erythrocyte (p. 482)
leukocyte (p. 483)
pus (p. 483)
platelet (p. 483)
anemia (p. 484)
aorta (p. 487)
arteriole (p. 488)
vasodilation (p. 488)
vasoconstriction (p. 488)
venule (p. 490)
systolic pressure (p. 491)
diastolic pressure (p. 492)
hypertension (p. 492)
lymph (p. 493)
lymph node (p. 493)
spleen (p. 493)
thymus (p. 494)
pericardium (p. 496)
coronary blood vessel (p. 496)
semilunar valve (p. 496)
atrioventricular valve (p. 496)
chordae tendineae (p. 496)
cardiac cycle (p. 497)
diastole (p. 497)
systole (p. 497)
myogenic muscle (p. 498)
sinoatrial (SA) node (p. 499)
atrioventricular (AV) node (p. 499)
Purkinje fibre (p. 499)
electrocardiograph (p. 499)
arteriosclerosis (p. 501)
plaque (p. 501)
atherosclerosis (p. 501)
coronary artery disease (CAD) (p. 501)
angina (p. 501)
myocardial infarction (p. 502)
angioplasty (p. 502)
bypass surgery (p. 503)
cardiac catheterization (p. 504)
angiogram (p. 504)
computerized tomography (CT) scan (p. 505)
positron emission tomography (PET) scan (p. 505)
magnetic resonance imaging (MRI) scan (p. 506)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or postgraduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select two careers related to the structure and function of the circulatory system that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



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CHAPTER 11 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which of the following best describes the circulating fluid that is present in animals with an open circulatory system? (11.1) K/U
   (a) plasma
   (b) hemolymph
   (c) blood separated from tissue fluid
   (d) lymph
2. In animals, the _____ circuit circulates blood to the lungs for gas exchange with the external environment. (11.1) K/U
   (a) pulmonary
   (b) systemic
   (c) renal
   (d) gastric
3. Which component of blood is an intercellular matrix? (11.2) K/U
   (a) red blood cells
   (b) white blood cells
   (c) platelets
   (d) plasma
4. What are three types of granular leukocytes? (11.2) K/U
   (a) lymphocytes, monocytes, macrophages
   (b) red blood cells, white blood cells, platelets
   (c) neutrophils, eosinophils, basophils
   (d) macrophages, monocytes, neutrophils
5. Which of the following causes a decrease in the diameter of arterioles that, in turn, decreases the blood flow to tissues? (11.3) K/U
   (a) vasodilation
   (b) vasoconstriction
   (c) vascular compression
   (d) systolic pressure
6. What type of blood vessel carries deoxygenated blood from the body tissues back to the heart? (11.3) K/U
   (a) veins
   (b) capillaries
   (c) arteries
   (d) aorta
7. Which valves of the heart are located where the ventricles meet the pulmonary arteries and the aorta? (11.4) K/U
   (a) chordae tendineae
   (b) coronary
   (c) atrioventricular
   (d) semilunar
8. Which node initiates the heartbeat and maintains the regular rhythm? (11.4) K/U
   (a) cardiac node
   (b) sinoatrial node
   (c) atrioventricular node
   (d) Purkinje node
9. Which of the following is used to measure blood pressure? (11.3) K/U
   (a) spirometer
   (b) sphygmomanometer
   (c) stereoscope
   (d) ammeter
10. Which of the following is considered bad cholesterol? (11.5) K/U
    (a) fatty acid
    (b) enzyme
    (c) high-density lipoprotein (HDL)
    (d) low-density lipoprotein (LDL)

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

11. A ventricle is a chamber of the heart that receives blood from the body. (11.1) K/U
12. Amphibians developed a four-chambered heart as animals evolved in size and complexity. (11.1) K/U
13. The main function of erythrocytes is to carry oxygen from the lungs to the body cells and to carry carbon dioxide from the body cells back to the lungs to be expelled. (11.2) K/U
14. Systolic pressure is the term that indicates the lower limit of blood pressure. (11.3) K/U
15. Under normal conditions, a cardiac cycle takes about 0.8 s. (11.4) K/U
16. A CT scan uses gamma rays instead of X-rays to produce a cross-sectional image of the body. (11.6) K/U
17. The two hormones insulin and glucagon maintain a balance of the blood glucose level in the body. (11.7) K/U

To do an online self-quiz,
GO TO NELSON SCIENCE

CHAPTER 11 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. Which of the following organisms has an open circulatory system? (11.1) K/U
   (a) sponge
   (b) snail
   (c) earthworm
   (d) trout
2. Which of the following is a fluid that results when the blood cells, platelets, and fibrinogen have been removed from whole blood? (11.2) K/U
   (a) serum
   (b) lymph
   (c) globulin
   (d) hemoglobin
3. Which of the following carry blood away from the heart toward the body tissues? (11.3) K/U
   (a) veins and venules
   (b) arteries and arterioles
   (c) veins and arterioles
   (d) arteries and venules
4. Which is the period of relaxation and filling of the heart in the cardiac cycle? (11.4) K/U
   (a) circulation
   (b) systole
   (c) vasodilation
   (d) diastole

Match each term on the left with the most appropriate description on the right.

5.

(a) plasma	(i) small cell fragments that are essential in blood clotting
(b) erythrocytes	(ii) hormone produced by the kidneys that stimulates the production of red blood cells
(c) leukocytes	(iii) liquid component of blood
(d) erythropoietin	(iv) white blood cells
(e) platelets	(v) red blood cells (11.2) K/U

6.

(a) leukemia	(i) universal donor
(b) anemia	(ii) universal recipient
(c) type O blood	(iii) condition of higher than normal white blood cell count
(d) type AB blood	(iv) condition of lower than normal red blood cell count (11.2) K/U

7

(a) papillary muscle	(i) muscle between the left and right ventricles
(b) chordae tendineae	(ii) largest vessel that carries blood away from the heart
(c) left ventricle	(iii) tough cords that connect the muscles to the valves
(d) septum	(iv) vessel that carries blood from the lungs to the heart
(e) aorta	(v) chamber of the heart that sends oxygenated blood to the body
(f) pulmonary vein	(vi) vessel that carries blood from upper tissues to the heart
(g) right atrium	(vii) muscle found inside the ventricle that controls the valves
(h) superior vena cava	(viii) chamber of the heart that receives blood from the body (11.4) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

8. All animals have a system of vessels and tubes called a circulatory system. (11.1) K/U
9. Hemolymph is a mixture of blood and tissue fluid. (11.1) K/U
10. Control of blood flow can help regulate body temperature. (11.3) K/U
11. The atria of the heart have thicker walls than the ventricles. (11.4) K/U
12. The pericardium is a double-layered membrane that covers the lungs. (11.4) K/U
13. Purkinje fibres are attached to the papillary muscles on the inside of the ventricles. (11.4) K/U
14. Coronary bypass surgery is the least invasive treatment for coronary artery disease (CAD). (11.5) K/U

Write a short answer to each question.

15. List three functions of a circulatory system. (11.1) K/U
16. What are the most common ions found in plasma? (11.2) K/U
17. What blood cells work to combat infection in the event of a cut or pimple? (11.2) K/U
18. Use a T-chart to compare an arteriole to a capillary. (11.3) K/U C
19. As part of the circulatory system, the lymphatic system ensures that what is maintained? (11.3) K/U
20. **Figure 1** shows a diagram of the human heart. In your notebook, match the following labels to the appropriate letter in Figure 1: septum, left ventricle, left atrium, aorta, semilunar valves, right atrium, right ventricle, atrioventricular valves, inferior vena cava, superior vena cava. (11.4) K/U

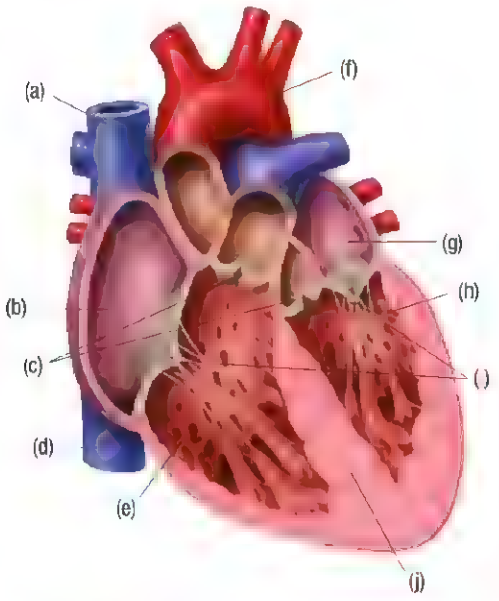


Figure 1 The human heart

21. Why is myogenic muscle considered a safety mechanism for the human body? (11.4) K/U
22. List six major risk factors that contribute to CAD. (11.5) K/U
23. Why is it important to receive treatment as early as possible after a myocardial infarction? (11.5) K/U
24. What is the difference between an invasive test and a non-invasive test? Give an example of each. (11.6) K/U
25. What is another name for a cardiac angiography, and how is it performed? (11.6) K/U
26. Why are MRI scans considered safer than X-rays, CT scans, and PET scans? (11.6) K/U
27. What is the function of insulin? (11.7) K/U
28. How does glucagon decrease blood glucose levels in the body? (11.7) K/U
29. What are two possible causes of diabetes? (11.7) K/U
30. Compare and contrast type 1 and type 2 diabetes. (11.7) K/U

Understanding

31. Explain how the structure of a vein contributes to its role in the circulatory system. (11.1) K/U T/I
32. Use a graphic organizer to compare and contrast open circulatory systems and closed circulatory systems. (11.1) K/U C
33. Animals have evolved over the years in both size and complexity. The heart of animals has evolved from a two-chambered to a four-chambered heart. Draw simple labelled diagrams of the heart of a fish, an amphibian, a reptile, and a mammal. (11.1) K/U C
34. Erythrocytes, or red blood cells, have a unique and peculiar shape. How does their shape suit their function? (11.2) K/U T/I
35. How does erythrocytes' lack of nucleus help them perform their functions? (11.2) K/U T/I
36. Pus may be unpleasant to look at, but it is actually a good sign. It means that your body is doing what? (11.2) K/U
37. Copy **Table 1** into your notebook and fill in the missing information. (11.2) K/U

Table 1

Blood type	Can receive from	Can donate to
A+	A+ A− O+ O−	
A−	A− O−	
B+		B+ AB+
B−	B− O−	B+ B− AB+ AB−
AB+		
AB−	A− B− AB− O−	
O+		A+ B+ AB+ O+
O−	O−	

38. Explain how vasoconstriction allows the body to efficiently use the amount of blood available. (11.3) K/U

39. Arrange the following blood vessels in order, from those vessels with the greatest pressure to those with the least: venules, arteries, veins, arterioles, and capillaries. (11.3) K/U T/I

40. Arteries and veins vary in composition, location, and function. Compare and contrast the structure and function of arteries, capillaries, and veins. (11.3) T/I

41. Explain the roles of the spleen. What are the implications for someone whose spleen has been removed? (11.3) K/U

42. Tonsils are the two round bumps of lymphoid tissue located in the back of the throat. Why could it be argued that tonsils should not be removed? (11.3) T/I

43. If a doctor heard a *lubb-shh-DUBB* or *lubb-dubb-rumble* when listening to a patient's heart instead of the normal *lubb-DUBB* sound, what structure in the heart is likely not working properly and what is likely going wrong? (11.4) K/U T/I

44. Fill in the blanks to complete one cardiac cycle. (11.4) K/U
    (a) The left and right _____ fill with blood from the body and the lungs.
    (b) Both the left and the right atria contract at the same time, moving blood into the _____.
    (c) The left and right ventricles fill while the atria _____.
    (d) The left and right ventricles contract, and the _____ valves snap shut. As the blood is pushed out, the pressure opens the _____ valves.
    (e) Ventricular relaxation now occurs as the _____ valves close so that the blood does not wash back into the relaxed ventricles

45. The heart is surrounded by the pericardium. How does the structure of the pericardium suit its function? (11.4) K/U T/I

46. Heart disease is one of the leading causes of death in Canada. Identify three major lifestyle changes recommended to prevent or alleviate heart attacks and CAD. (11.5) K/U

47. List some warning symptoms that individuals may experience before they have a heart attack. Why are these symptoms not always recognized as symptoms of an impending heart attack? (11.5) K/U T/I

48. Non-invasive tests are done for diagnostic purposes only. These tests are utilized to identify a problem or to confirm a suspected problem. Non-invasive tests include CT, PET, and MRI scans. Use a graphic organizer to compare and contrast CT, PET, and MRI scans. Be sure to include potential side effects. (11.6) K/U C

49. Cardiac calcium scoring is not a routine test because in most cases your doctor can get a sense of your heart's condition through a physical exam or other tests. When might a doctor order this type of test? (11.6) K/U T/I

Analysis and Application

50. How could having a closed circulatory system be an advantage for an organism? (11.1) K/U T/I

51. Why would a four-chambered heart be better than a three chambered heart for a terrestrial organism that needs to run to catch its prey? (11.1) K/U T/I

52. Polycythemia is the over-production of red blood cells. What problems could this create for the circulatory system? (11.2) K/U T/I A

53. A pregnant woman is Rh-negative and her unborn baby is Rh positive. There are times during pregnancy and delivery when the baby's blood can enter the mother's bloodstream and the different types of blood mix, creating antibodies. This generally does not cause problems in the first pregnancy but can in subsequent pregnancies. Why? (11.2) K/U T/I A

54. Thrombocytopenia is a term that doctors use for a reduced platelet count. Why would a doctor be concerned if a patient had thrombocytopenia? (11.2) K/U T/I A

55 Why might someone who has a severe infection need a plasma-only transfusion? (11.2) K/U T/I A

56. Create a graph that best illustrates the volumes of the four basic components of blood. Why did you choose your particular style of graph? (11.2) K/U T/I C

57. A patient reports symptoms of tiredness, dizziness, and unusual fatigue. Based on what you have learned in this unit, what two possible diagnoses might the doctor consider before asking another question? What symptoms might the doctor inquire about to help narrow his or her diagnosis? (11.2, 11.3) K/U T/I A

58. Blood doping is an illegal practice that some athletes use. They have blood cells removed a few weeks prior to competition and store them. These blood cells are injected back into the athlete just before the competition. Why would this give some athletes an advantage? Which type of sports would they most likely be involved in? (11.2) K/U T/I A

59. Study the data in **Table 2** and answer the questions that follow. (11.2) K/U T/I A

Table 2

Blood cell	Patient 1	Patient 2	Patient 3
Erythrocytes	4 500 000	5 100 000	3 200 000
Leukocytes			
Neutrophils	4300	8450	5450
Lymphocytes	1750	3600	1900
Monocytes	540	900	480
Eosinophils	275	630	320
Basophils	80	145	73
Platelets	100 000	275 000	290 000

(a) Which patient is likely suffering from anemia? Explain your answer.

(b) Which patient is likely fighting an infection? Explain your answer.

(c) Which patient may have problems with extended bleeding even from small cuts? Explain your answer.

60. Why could the names "blood substitute" or "artificial blood" be considered inappropriate? (11.2) K/U T/I C

61. **Figure 2** is a diagram of a blood vessel. What type of blood vessel is it? How do you know? (11.3) K/U T/I

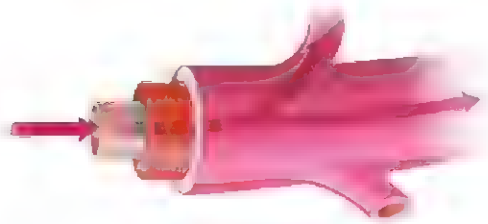


Figure 2

62. Propose a possible explanation for why the soldier in the picture collapsed (**Figure 3**). (11.3) K/U T/I A

Figure 3 A soldier from the Royal Danish guard faints while standing at attention.

63. "White coat hypertension" occurs when a patient gets an unusually high blood pressure reading only in the doctor's office or hospital. How does this differ from hypertension? (11.3) K/U T/I A

64. The doctor tells you that your blood pressure is consistently 140/90. What does this mean, and what, if any, lifestyle changes will you need to make? (11.3) K/U T/I A

65. Could low blood pressure be as much of a medical concern as high blood pressure? Why? (11.3) T/I

66. The locations of the highest and lowest blood pressure in the circulatory system are both near the heart. Explain this statement. (11.3) K/U T/I

67. The amount of blood pumped by the heart is called cardiac output. This is a measure of the volume of blood pumped from each ventricle per unit of time. It is also a measure of the level of oxygen delivery to the body. Two factors affect cardiac output—heart rate and stroke volume. Stroke volume is the amount of blood forced out of the heart with each heartbeat.

Cardiac output can be calculated by multiplying stroke volume and heart rate. The average person has a stroke volume of about 70 mL and a resting heart rate of about 70 beats/min. Therefore, the average person has a cardiac output of 70 mL/beat × 70 beats/min = 4900 mL/min. Take your pulse for one minute. Using your heart rate and the average value for stroke volume, estimate your actual cardiac output. Suggest reasons why it is likely higher or lower than the sample rate. (11.4) T/I A

68. Sketch the graph in **Figure 4** into your notebook. On the same graph sketch the ECG pattern showing the P wave, the QRS complex, and the T wave correlated with the variations in atrial and ventricular pressure. (11.4) K/U C A

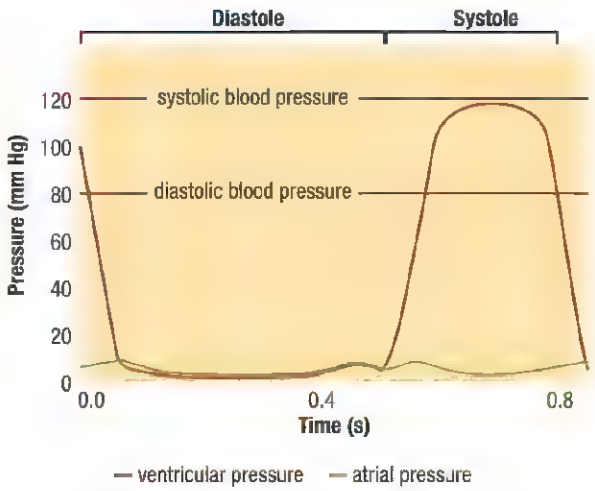


Figure 4

69. Use simple sketches of ECG patterns to compare a normal heartbeat with a heartbeat that has a weak ventricular contraction. (11.4) K/U T/I C A

70. The contraction of the ventricles begins at the tip or bottom of the heart. Why is this necessary? (11.4) K/U T/I

71. **Figure 5** shows the average heart rate for a group of students before, during, and after exercise. Carefully study the graph and answer the questions that follow. (11.4) K/U T/I A

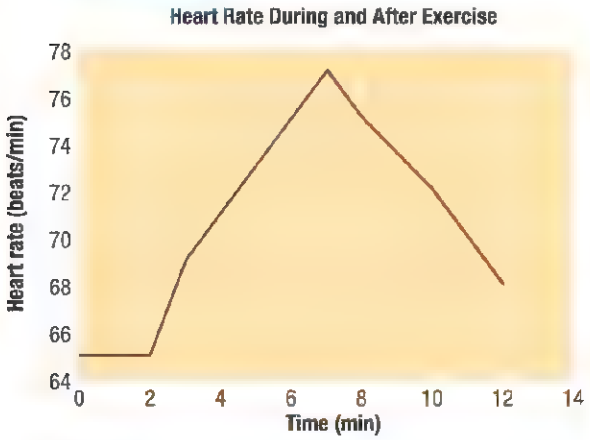


Figure 5

(a) What was the average resting heart rate of the group?
(b) At what times were the heart rates measured?
(c) What was the duration of the exercise?
(d) What was the average heart rate at 9 minutes?
(e) The recovery time is the time required for the heart rate to return to normal after exercise. What is the estimated recovery time in this investigation?

72. Once an individual has been diagnosed with coronary artery disease, his or her life will change. Consider the possible medical, social, and economic impacts and make a list of possible life changes this person will experience. (11.5) T/I A

73 Suppose your aunt has returned home from hospital after a heart attack. You have been asked to research key measures in preventing another heart attack. Create a pamphlet that the doctor could give your aunt about altering her lifestyle. It should include information on smoking, cholesterol, blood pressure, obesity, diabetes, physical activity, diet, and stress. K/U T/I C A

74. Private clinics are using medical imaging (CT, PET, MRI) technologies and tests for screening purposes—looking for suspicious signs in people who are not showing any symptoms—rather than for diagnostic purposes. Based on what you know about this kind of technology, what are the potential downsides to using technology in this way? (11.6) K/U T/I

Evaluation

75. When doctors want to know your blood glucose levels, they use a blood test that requires you to fast (not eat or drink anything but water) for 12 h prior to the blood being drawn. Why do you think this is necessary? (11.7) T/I

76. Given what you have learned about the evolution of the circulatory system and heart of members of the animal kingdom, compose a paragraph indicating the reasons for a more complex circulatory system and heart as evolution progressed. (11.1) K/U T/I C

77. Some Canadian physicians believe that the government should regulate the amount of sodium in food made available to consumers. Canadians currently consume more than double the highest recommended daily amount of 2300 mg. Government intervention could have both advantages and disadvantages for consumers. Explain. (11.3) T/I A

78. If you needed medical imaging of your heart, would you prefer to have a CT scan, a PET scan, an MRI scan, or a Doppler ultrasound? Explain your reasoning (11.7) K/U T/I

Reflect on Your Learning

79. Think about all of the medical technologies discussed in this chapter that help us understand the human circulatory system and assist in the diagnosis and/or treatment of circulatory system disorders. Which two of these technologies do you think are most important? Explain your reasoning. (11.7) K/U T/I

80. As a result of HIV and hepatitis infections that were transmitted through contaminated blood, the Federal Government established a Royal Commission of Inquiry on the Blood System in Canada. The report of the Royal Commission was submitted in 1997 and led to the establishment of Canadian Blood Services, an agency that manages the supply of blood products in all of Canada, with the exception of the province of Quebec. This agency is responsible for the safety of all blood products that are obtained and used. How safe do you think the blood supply is in Canada? If you required a blood transfusion, do you feel confident that the blood products you would receive would not be contaminated with possible infectious organisms? Which risk do you think is greater, the risk of contaminated blood or the risk associated with not receiving blood? Explain your answer. T/I A

81. Blood products used for transfusion are obtained from blood donors, volunteers who provide a unit (about 450 mL) of their blood through the blood donation process. Have you donated or considered donating whole blood or other blood products? Explain why or why not. T/I A

82. This chapter describes a few disorders and diseases that can affect the circulatory system. K/U T/I A
    (a) Do you consider yourself too young to develop any of these conditions? Explain your answer.
    (b) Which of these diseases or disorders concerns you most?
    (c) Which of these diseases or disorders do you think are preventable?
    (d) What can you do to reduce your risk of developing these preventable conditions?
83. Think about how your understanding of the circulatory system has changed as a result of studying this chapter. Create a three-column table with the following headings: What I Already Knew, My New Learning, and What I'd Like to Know. In the first column, summarize what you knew from previous science courses or informal learning. In the second column, describe any additional information you learned in this chapter. In the third column, create questions that represent what you would like to know more about. K/U T/I

Research

GO TO NELSON SCIENCE

84. Despite donations and blood drives, hospitals and blood banks always seem to have dangerously low blood supplies. Researchers have been working on a blood substitute for many years and have not yet been successful in developing one that is safe. Use the Internet and other sources to research the latest advancements in blood substitutes and artificial blood. Write a brief report of your findings. T/I C
85. Kwashiorkor is a disorder among children who have a chronic deficiency of protein in their diet. One of the characteristic symptoms is a distended and severely swollen abdomen (**Figure 6**). Use the Internet and other sources to research kwashiorkor. Write a brief report of your findings. Be sure to explain the connection between insufficient protein in the diet and the accumulation of tissue fluid leading to abdominal swelling. T/I C A

Figure 6 A child suffering from kwashiorkor

86. Varicose veins develop from damage to the venous valves and the veins of the lower legs. Individuals who spend a lot of time on their feet experience varicose veins. Use the Internet and other sources to research treatments for varicose veins. Compare these treatments by explaining each method, where it is performed, its effectiveness, and possible side effects. Use diagrams if they are helpful. T/I C A
87. Use the Internet and other sources to research the following diseases of the lymphatic system: Hodgkin's lymphoma and non-Hodgkin's lymphoma. Compare and contrast these diseases in terms of symptoms, diagnosis, treatment, and prognosis. T/I A
88. Patients receiving chemotherapy are often given shots of pegfilgrastim. Using the Internet, find out what pegfilgrastim is, why it is needed before and during chemotherapy, what it is supposed to do, and what the risks of taking this drug are. Write a one-page report explaining this information for potential chemotherapy patients. T/I C A
89. Results from a CBC (complete blood count) show high levels of plasma cells and low levels of red blood cells (anemia). Other blood tests show high levels of calcium and certain blood proteins. The doctor suspects multiple myeloma. Using the Internet and other sources, research multiple myeloma. Create a visual media presentation for the class detailing the following: T/I C A
    (a) description
    (b) symptoms
    (c) diagnosis
    (d) classification and staging
    (e) treatment and prognosis
90. Use the Internet and other sources to research the role of rhesus monkeys in discovering the rhesus factor. T/I A
    (a) Explain how the discovery of the rhesus factor came about.
    (b) What does your research tell you about the nature of scientific discovery?
91. A new treatment for cardiac arrest patients is to induce hypothermia by cooling the body using a chilled water blanket or torso vest and leg wraps. Use the Internet and other sources to research this practice, which is called therapeutic hypothermia. How do these devices induce hypothermia? Why is this practice used? How effective is therapeutic hypothermia in post–cardiac arrest treatment? T/I C A

UNIT 4 UNIT TASK

Health and Fitness Profile and Plan

The structures and functions of the digestive, respiratory, and circulatory systems all play a major role in the health and fitness of an individual.

Health and fitness are closely related concepts. The term "health" is usually used to refer to the total state of mental, physical, and social well being, rather than simply the absence of disease or disability. Fitness, often called physical fitness, is the ability to function appropriately in the normal environment. You can be fit without being healthy, but you cannot be healthy without being fit. Athletes may train to the point of extreme physical fitness that may make them more susceptible to illnesses or injuries. For example, very low body fat in female gymnasts can disrupt menstrual cycles. A healthy person will have an appropriate level of physical fitness. Being fit will not guarantee that you will live longer, but it will contribute to overall health and provide an improved quality of life.

There are two types of fitness: health-related and skill-related. Health-related fitness includes factors such as cardiovascular fitness, strength, flexibility, muscular endurance, and body composition. Skill-related fitness includes agility, speed, reaction time, balance, and coordination. These factors are usually associated with specific activities such as sports, outdoor activities, or occupations that require specific physical skills (**Figure 1**).

Figure 1

Based on these factors, there are many criteria that may be used to assess and evaluate an individual's health and fitness. These criteria may then be used as the basis of a health and fitness profile and a plan for addressing any health and fitness problems.

Purpose

You will play the role of a health and fitness counsellor, using the knowledge and skills you have gained throughout the unit to complete the following:

- Create a health and fitness profile of an individual.
- Identify areas that need improvement, and set achievable goals.
- Create a plan or program for achieving the goals.

Procedure

SKILLS HANDBOOK A1.2, A2.1

Part A: Create a Health and Fitness Profile

1. Identify and describe an individual (real or fictitious) for whom you will prepare a health and fitness profile. The individual may be you or a friend, or an individual who has specific health and fitness requirements, such as an Olympic athlete, a person with diabetes, a lung transplant patient, or a bypass surgery patient.
2. If your chosen individual has different or unique health and fitness requirements, identify the requirements and explain the need for them.
3. Select from the following criteria to create a representative description of the individual's health and fitness:
   - sex (i.e., male/female)
   - height
   - weight
   - blood pressure
   - resting heart rate
   - blood glucose level
   - body mass index (BMI)
   - percentage body fat (skinfold)
   - body composition (water, protein, fat)
   - basal metabolic rate (BMR)
   - VO_2max
   - aerobic fitness
   - muscle strength
   - muscle endurance
   - flexibility
   - relevant diseases or disorders
   - physical disabilities
   - lifestyle factors (for example, activity level, diet, smoking, alcohol consumption)
   - analysis of the individual's diet for a week

4. Using the criteria you have selected, create a health and fitness profile for the individual. You may use real or fabricated data.
   - If you are using real data, be sure to select criteria you can measure with readily available equipment.
   - If you are fabricating data, use the Internet or other sources to research ranges of normal values for the criteria you selected. Depending on the fictitious individual you chose, the data may fall within or outside these ranges, but should be realistic.

   When the analysis is completed, create a report outlining the possible impacts of the individual's lifestyle choices on his or her digestive, respiratory, and circulatory systems. The profile should be presented in an appropriate format, such as a chart or table.

Part B: Identify Areas of Improvement and Set Goals

5. Use the Internet and other sources to research the ranges of normal values for the criteria you have selected, if you have not done so already in Step 4. For example, the average blood pressure for a young adult is 120/80.
6. Identify the areas in the health and fitness profile that could be improved.
7. Establish achievable goals for the areas you have identified for improvement. For example, if the individual's blood pressure is 130/90, the goal might be to reduce it to lower values.

Part C: Create a Health and Fitness Plan

8. Create a plan for achieving the goals established in Part B. The plan should include all measures that will contribute to the achievement of the goals. These measures should be categorized under the following three headings: diet, physical activity, and lifestyle.
9. The plan should identify a time frame that will allow sufficient time for the achievement of the goals.
10. Compile the profile from Part A, the recommendations and goals from Part B, and the plan, and present them as a report from you, the health and fitness counsellor.

Analyze and Evaluate

(a) Explain your choice of criteria for the health and fitness profile. Why did you choose these particular criteria? T/I

(b) Why do you think it is important to include a time frame in the health and fitness plan? T/I A

(c) What aspects of the plan do you think would be most challenging for the individual to put into action? Explain your answer. T/I A

Apply and Extend

(d) If you prepared a health and fitness profile for yourself, what areas do you think would need improvement? T/I A

(e) Contact a fitness coach or fitness counsellor in your area and ask to interview him or her. Prepare questions that will provide the following information:
   - educational and other training requirements
   - physical skills required
   - enjoyable (and not so enjoyable) aspects of the career

   Alternatively, use the Internet and other sources to research the career. T/I C A

ASSESSMENT CHECKLIST

Your completed Unit Task will be assessed using the following criteria:

Knowledge/Understanding

- ✓ your understanding of how the health and fitness of an individual is determined by the structure and function of the digestive, respiratory, and circulatory systems
- ✓ your knowledge of the scientific/biological basis of the health and fitness criteria (that is, what they indicate about an individual's health and fitness)
- ✓ your understanding of the causes of specific diseases or disorders, if applicable, and how they affect health and fitness

Thinking/Investigation

- ✓ your ability to find and select relevant information
- ✓ your evaluation of the authority (credibility, reputation, objectivity, and so on) of information sources
- ✓ your ability to evaluate the accuracy and currency of information from various sources
- ✓ the evidence on which your recommended actions in the health and fitness plan are based

Communication

- ✓ the organization and clarity of the information in the health and fitness profile
- ✓ the appropriateness and effectiveness of the chosen format for the health and fitness profile
- ✓ the organization and clarity of the health and fitness plan

Application

- ✓ the quality of the profile (do the selected criteria constitute an appropriate profile?)
- ✓ the feasibility of the goals (are the goals achievable?)
- ✓ the appropriateness and practicality of the actions recommended in the plan (will the actions enable achievement of the goals?)

UNIT 4 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which of the following describes a nutrient? (9.1) K/U
   (a) something that an organism ingests
   (b) a chemical used for growth, repair, and energy
   (c) a chemical that gets broken down by an organism
   (d) all of the above
2. Which are the six main essential nutrients? (9.2) K/U
   (a) carbohydrates, fats, proteins, lipids, water, vitamins
   (b) carbohydrates, proteins, lipids, water, vitamins, minerals
   (c) monosaccharides, triglycerides, proteins, amino acids, water, minerals
   (d) carbohydrates, triglycerides, protein, lipids, vitamins, minerals
3. Which of the following are the building blocks of proteins? (9.2) K/U
   (a) glucose and other simple sugars
   (b) enzymes
   (c) lipids and glycogen
   (d) amino acids
4. What is not a role of saliva? (9.4) K/U
   (a) aids in swallowing
   (b) begins to chemically digest starch
   (c) helps you taste food
   (d) begins to chemically digest lipids
5. What are the three sections of the small intestine? (9.5) K/U
   (a) duodenum, jejunum, sigmoid colon
   (b) ascending colon, transverse colon, descending colon
   (c) duodenum, jejunum, ileum
   (d) villi, microvilli, lacteal
6. Which of the following is a typical cause of diarrhea? (9.6) K/U
   (a) *E. coli* in the water supply
   (b) food contaminated with *Listeria monocytogenes*
   (c) parasites
   (d) all of the above
7. Which statement is not true of vomiting? (9.6) K/U
   (a) It is initiated from a signal in the brain.
   (b) It is a symptom of another ailment.
   (c) It is never caused by a bacterial infection.
   (d) It can cause dehydration.
8. The human body stores energy in the form of
   (a) ADP
   (b) glucose
   (c) ATP
   (d) heat (10.1) K/U
9. Where does gas exchange take place in the body? (10.1) K/U
   (a) in the lungs
   (b) in the lungs and body cells
   (c) in the lungs and blood
   (d) all of the above
10. Oxygen cannot diffuse across a respiratory membrane unless which condition is met? (10.2) K/U
    (a) The oxygen partial pressure is over 20 kPa.
    (b) The oxygen is dissolved in a liquid.
    (c) The oxygen is linked to an enzyme.
    (d) The membrane is inside the body.
11. The gills of fish push oxygen-rich water in which direction? (10.2) K/U
    (a) toward the heart
    (b) away from the lungs
    (c) in the same direction as capillary blood flow
    (d) in the opposite direction to capillary blood flow
12. This percentage of oxygen in the blood is dissolved in the plasma and not carried by hemoglobin. (10.3) K/U
    (a) 1.5 %
    (b) 98.5 %
    (c) 100 %
    (d) none of the above
13. Which chemical in cigarette smoke accounts for the addictiveness of cigarettes? (10.4) K/U
    (a) tar
    (b) carbon monoxide
    (c) carbon dioxide
    (d) nicotine

14. Which feature do all circulatory systems of all animals have? (11.1) K/U
    (a) veins and arteries
    (b) tubes that carry food and oxygen
    (c) a pump
    (d) a fluid that contains hemoglobin
15. Why is a two-circuit circulatory system more efficient than a one-circuit system? (11.1) K/U
    (a) Oxygenated and deoxygenated blood are separated.
    (b) Oxygenated and deoxygenated blood are mixed.
    (c) The heart pumps only oxygenated blood.
    (d) The heart pumps only one kind of blood (oxygenated or deoxygenated) at a time.
16. Which of the following would result in an increased ability of blood to carry oxygen? (11.2) K/U
    (a) an increase in the number of erythrocytes
    (b) an increase in the number of leukocytes
    (c) a decrease in the amount of blood plasma
    (d) a decrease in the number of erythrocytes
17. A person with type A blood could
    (a) donate blood to a person with type O blood
    (b) receive blood from a type O or type AB donor
    (c) donate blood to a type AB recipient
    (d) receive blood from a type A or type B donor (11.2) K/U T/I
18. Which blood vessels have smooth muscle and can be controlled by the nervous system? (11.3) K/U
    (a) arteries and arterioles, but not veins
    (b) veins, but not arteries
    (c) both arteries and veins
    (d) capillaries
19. Which of the following best describes atherosclerosis? (11.5) K/U
    (a) hardening of the arteries due to poor diet
    (b) hardening of the arteries due to plaque buildup
    (c) hardening of the arteries due to any cause
    (d) hardening of the arteries due to poor circulation
20. Which of the following is the greatest risk factor for coronary artery disease? (11.5) K/U
    (a) a high level of lipoprotein
    (b) a high level of HDL lipoprotein
    (c) a high level of LDL lipoprotein
    (d) a low level of LDL lipoprotein

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

21. The metabolic rate of a typical human being tends to increase with age in adults. (9.1) K/U
22. A chain of amino acids is called a complex carbohydrate. (9.2) K/U
23. The digestion of the carbohydrates in a potato begins in the stomach. (9.4) K/U T/I
24. Active transport across a membrane requires energy to move a substance against a concentration gradient. (9.5) K/U
25. Most of the water that enters the large intestine passes out of the body. (9.5) K/U
26. Ventilation takes place in both the lungs and the body cells. (10.1) K/U
27. When you inhale, your diaphragm moves down, expanding the volume of the thoracic cavity and creating negative pressure that draws in air. (10.2) K/U
28. The partial pressure of oxygen in the alveoli is considerably greater than the partial pressure of oxygen in both the atmosphere and the blood in the capillaries entering the lungs. (10.3) K/U
29. When you run hard, increased carbon dioxide raises the pH in the blood to signal the breathing rate and heart rate to increase. (10.3) K/U A
30. The most serious consequence of chronic pulmonary obstructive disease (COPD) is the destruction of alveoli from emphysema. (10.4) K/U
31. The most important function of an artificial lung is to remove carbon dioxide from the blood. (10.5) K/U
32. Insects use an open circulatory system to transport food and oxygen to their body cells. (11.1) K/U
33. Salt contributes to hypertension by causing water to diffuse from the blood to the tissue fluid. (11.3) K/U
34. Veins typically have a larger diameter than arteries, causing venous blood to be lower in pressure than arterial blood. (11.3) K/U
35. All arteries in the body contain oxygenated blood, except for the pulmonary artery. (11.4) K/U T/I
36. The heartbeat is initiated by a cluster of cells in the right atrium that receive an electrical signal from the brain. (11.4) K/U

UNIT 4 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. What best describes a nutrient? (9.1) K/U
   (a) anything that you eat
   (b) chemicals that an organism uses to combat disease and resist infections
   (c) chemicals that an organism uses for growth, repair, or energy
   (d) anything an organism requires to live
2. Glycogen, cellulose, and glucose are examples of what kind of nutrient? (9.2) K/U
   (a) carbohydrates
   (b) vitamins
   (c) proteins
   (d) lipids
3. Where are fats broken down in the human digestive system? (9.4, 9.5) K/U
   (a) in the stomach
   (b) in the small intestine
   (c) in the large intestine
   (d) in the mouth
4. What does bile do to aid digestion? (9.5) K/U
   (a) breaks down fats into individual fatty acids
   (b) emulsifies fats into tiny droplets
   (c) absorbs vitamins into the body
   (d) breaks down carbohydrates into individual sugars
5. Which of the following is used as an energy source in the human body? (10.1) K/U
   (a) ADP
   (b) ATP
   (c) hemoglobin
   (d) sodium
6. Which of the following has the greatest influence on breathing rate and heart rate? (10.3) K/U
   (a) the level of oxygen in the blood
   (b) the amount of hemoglobin in the blood
   (c) the level of carbon dioxide in the blood
   (d) none of the above
7. Nutrients move from the blood into cells from which kind of blood vessels? (11.3) K/U
   (a) veins
   (b) venules
   (c) arterioles
   (d) capillaries
8. Oxygenated blood is pumped from the heart to the rest of the body through which heart chamber? (11.4) K/U
   (a) left atrium
   (b) left ventricle
   (c) right atrium
   (d) right ventricle

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

9. Warm blooded animals need to consume a much larger amount of food per kilogram of body weight than cold-blooded animals. (9.1) K/U
10. The essential amino acids are the amino acids that humans can make on their own. (9.2) K/U
11. The stomach's main functions are to turn food to a semi-liquid and break down carbohydrates. (9.4) K/U
12. Food is largely digested in the ileum and absorbed in the duodenum. (9.5) K/U
13. In the human body, gas exchange takes place both in the lungs and in the body cells. (10.1) K/U
14. Respiratory membranes must always be kept dry to make sure gases can diffuse across the membrane boundaries. (10.2) K/U
15. The partial pressure of oxygen at sea level is the same as the partial pressure of oxygen at an elevation of 4000 m. (10.3) K/U
16. Emphysema involves destruction of alveoli so they are no longer capable of efficient gas exchange. (10.4) K/U
17. Oxygenated blood and deoxygenated blood are prevented from mixing in the heart of a fish. (11.1) K/U
18. Some leukocytes specialize in engulfing harmful substances that enter the body. (11.2) K/U
19. When you are cold, nerve impulses cause the smooth muscle in arterioles to widen and keep the body warm. (11.3) K/U
20. One semilunar valve keeps blood from backflowing from the aorta into the left atrium. (11.4) K/U

Match each item on the left with the most appropriate item on the right.

21.

(a) one-circuit closed system	(i) insects
(b) two-circuit system	(ii) amphibians
(c) open circulatory system	(iii) fish
(d) three-chambered heart	(iv) mammals and birds (11.1) K/U

22. (a) protein-rich fluid (i) leukocytes
    (b) cells that carry oxygen and carbon dioxide (ii) serum
    (c) contains no fibrinogen or other clotting factors (iii) erythrocytes
    (d) defend against infections (iv) plasma (11.2) K/U

Understanding

23. A warm-blooded rabbit and a cold-blooded snake both have a body mass of 2.5 kg. (9.1) K/U T/I
    (a) Which animal needs to consume more food?
    (b) Why does this animal need more food?
24. Humans need energy to carry out all life processes. (9.1) K/U T/I
    (a) What are some life processes that require energy?
    (b) What is the ultimate source of the energy that humans rely on to carry out life processes?
    (c) How is the energy from the source identified in (b) converted into a form that humans can use?
25. Breaking down a sugar molecule to obtain energy for running is an example of which part of metabolism? (9.1) K/U
26. A new food is chemically analyzed and found to be a protein. What kind of structure does this food have? (9 2) K/U T/I
27. A new food is chemically analyzed and found to be a complex carbohydrate. What kind of taste would you predict the food to have? (9.2) K/U T/I
28. A cook has created a complex stew from a variety of ingredients. The top of the stew has a layer of fat that stays liquid, even after the stew has cooled. (9.2) K/U T/I A
    (a) Is the fat layer likely to be saturated or unsaturated?
    (b) Does the fat layer come from an animal or a vegetable source? How do you know?
29. Many people think consuming fats is bad for their health. What is an example of a fat that is very good for a person's health? What benefits does it have? (9.2) K/U
30. A sample of partially digested food that contains carbohydrates, proteins, and fats is taken from the digestive system as it is ready to leave the stomach. (9 4) K/U
    (a) Which component of the food is likely to be most broken down and digested at this stage of digestion?
    (b) Which component of the food is likely to be only slightly broken down?
    (c) Which component of the food is likely to be completely undigested?
31. What would happen if the digestive enzyme pepsin were to leak out of the stomach into the surrounding tissue? How much damage would it likely cause? Explain. (9.4) T/I A
32. Digestion of proteins begins in the stomach with the enzyme pepsin. Then it continues with trypsin in the small intestine. (9.4, 9.5) K/U T/I
    (a) Why can pepsin not continue to digest proteins in the small intestine?
    (b) Would trypsin be able to function within the environment of the stomach? Why or why not?
33. A protein is broken down in the small intestine. (9.5) K/U
    (a) In which parts of the small intestine does the breakdown take place?
    (b) In which part of the small intestine is the broken-down protein absorbed?
    (c) In what form is the broken-down protein absorbed?
34. **Figure 1** shows the structure of the large intestine. Identify each labelled structure. (9.5) K/U

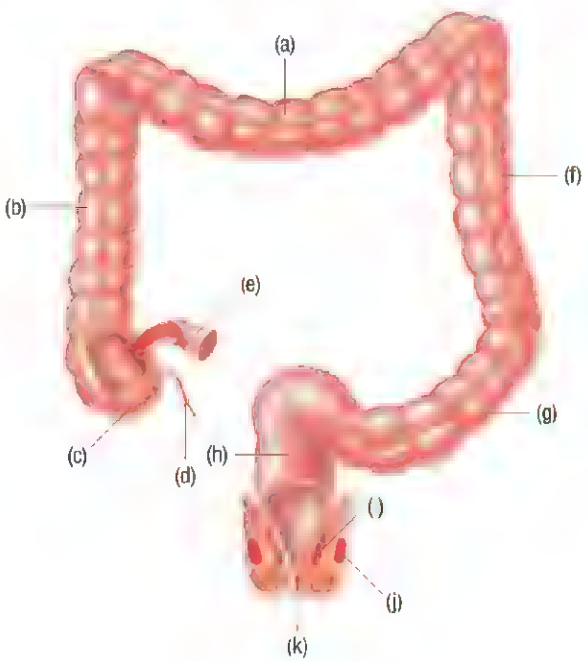


Figure 1 The large ntestine of a human

35. On an empty stomach, an athlete eats a performance bar that is made entirely of complex carbohydrates. When analyzed later, the athlete's blood contains no complex carbohydrates. Explain the lack of complex carbohydrates in his blood. (9.2, 9.5) K/U T/I A
36. Four passengers on a sailboat ride got seasick and ended up vomiting. Yet none of the passengers had an infection of any type. How do you explain what occurred? (9.6) K/U A
37. How is cellular respiration like charging a rechargeable battery? (10.1) K/U T/I A
38. Frogs are able to carry out gas exchange on their skin. (10.1) T/I
    (a) What advantage does this ability give frogs?
    (b) What is a disadvantage of being able to carry out gas exchange through the skin?
    (c) Why do frogs need lungs in addition to skin that acts as a respiratory membrane?
39. Use a T-chart to compare and contrast ventilation and gas exchange. (10.1) K/U C
40. In which locations of a fish's body does gas exchange take place? (10.2) K/U
41. Breathing takes energy. Which phase of the ventilation cycle requires more energy to be consumed—inhalation or exhalation? Explain. (10.2) K/U I/S
42. What is the advantage of locating the lungs deep inside the human body where they do not have easy access to an air supply? (10.2, 10.3) K/U T/I
43. Oxygen makes up 20.9 % of atmospheric pressure. The atmospheric pressure drops from 101.3 kPa at sea level to 80 kPa on a mountaintop. In moving to the mountaintop, will the partial pressure of oxygen go up, go down, or stay the same? If it changes, by how many kPa will it change? (10.3) K/U T/I
44. The gene that causes cystic fibrosis is responsible for making a protein that forms overly thick mucus. How is it possible for a person to carry a single defective gene for cystic fibrosis and not show symptoms of the disease? (10.4) K/U T/I
45. After the introduction of antibiotics in 1948, scientists thought that tuberculosis (TB) would disappear. What factors contribute to the continued presence of TB? (10.4) K/U T/I A
46. Some animals have circulatory systems and some do not. (11.1) K/U T/I
    (a) What is the most important factor in determining which animals have a circulatory system?
    (b) What kinds of animals would you expect to be able to survive without a circulatory system?
47. One of the functions of a circulatory system is to distribute heat in a warm-blooded animal. What is the source of the heat that the system distributes? (9.1, 10.1, 11.1) T/I A
48. Birds and mammals both have two-circuit circulatory systems. What are the primary advantages of a two-circuit system? (11.1) K/U T/I
49. An animal has an open circulatory system. Is the animal likely to be cold-blooded or warm-blooded? Explain. (11.1) T/I
50. Mammals and birds have a septum that separates the ventricles into a left and right cavity. How does the septum make a circulatory system more efficient? (11.1) K/U T/I
51. Albumins in blood plasma help control the water level in the bloodstream. When the albumin concentration in the plasma is high, in which direction would you expect osmosis to occur between the tissue fluid and the blood? (11.2) T/I
52. Raul claims that type O blood is both a universal donor and a universal recipient because type O erythrocytes have no markers on their surface. Is Raul correct? Explain. (11.2) K/U T/I C
53. A scientist is looking at blood cells in a microscope. The colour in the microscope is not very visible, so the scientist is not sure if the cells are red or white blood cells. What should the scientist look for to make identification certain? (11.2) K/U T/I
54. Blood plasma normally contains fibrinogen but not fibrin. (11.2) K/U T/I A
    (a) What is the difference between the two substances?
    (b) Why would it be unsafe to have fibrin travelling as a normal component of blood plasma?
    (c) At what point is fibrin put into use? What is the stimulus for creating fibrin?
55. Possibly harmful foreign material is mistakenly brought into the interior of some body cells. Which kind of blood cells will be called on to eliminate the foreign material? (11.2) K/U T/I A
56. The pulmonary veins, unlike all other veins, contain oxygenated blood. Why are the pulmonary veins not called arteries instead of veins? (11.3) K/U T/I
57. During a heart transplant, a heart can be taken out of a person's body and continue to beat on its own. How is this possible? Explain what keeps the heart beating even though it receives no input from the nervous system. (11.4) K/U T/I
58. Through a stethoscope, Rodney claims that he can hear the muscle contractions of his own heart. Is Rodney correct? Explain. (11.4) K/U T/I

Analysis and Application

59. A woman has a BMR of 8000 kJ. (9.1) T/I A
    (a) What is the difference in kilojoules in this woman's daily energy requirement between "no exercise" and "vigorous exercise"? (Refer to the Mini Investigation on page 398.)
    (b) How many more calories can this woman consume to maintain her daily energy requirement if she changes from "no exercise" to "vigorous exercise"?
    (c) What do you conclude from this example about activity and diet?

60. Cellulose is an indigestible carbohydrate that exists in plants that people eat to provide fibre. If cellulose is not used as an energy source and cannot be broken down into components for growth or repair, should it be considered a nutrient? Explain your thinking. (9.2) T/I A

61. A doctor has a patient who seems to be suffering from protein deficiency. This patient eats a strict vegan diet of expensive organic foods and no animal products. (9.2) T/I A
    (a) What might be the problem with the patient?
    (b) How might the doctor correct the problem?
    (c) Why does this problem not occur as often in vegetarians who eat dairy products?

62. A chemist breaks down cellulose (**Figure 2**), an indigestible polysaccharide, into individual glucose molecules (**Figure 3**). (9.2) T/I A

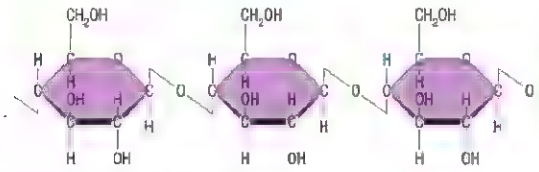


Figure 2 A fragment of cellulose

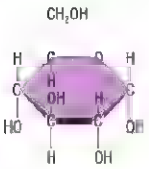


Figure 3 A glucose molecule

    (a) Will the glucose molecules from the cellulose be digestible or indigestible?
    (b) Which part of the cellulose chain must be making the entire chain indigestible?
    (c) Could the chemist create a digestible food from cellulose? Explain.

63. Some Aboriginal Canadians in southern Ontario traditionally grew the "three sisters" crops—corn, beans, and squash—together (**Figure 4**). Growing the three sisters was good for the soil, but it was also good for nutrition as the three crops were said to complement one another. What do you suppose is meant by the plants complementing one another? (**Hint**: Do all plants supply all essential amino acids?) (9.2) T/I A

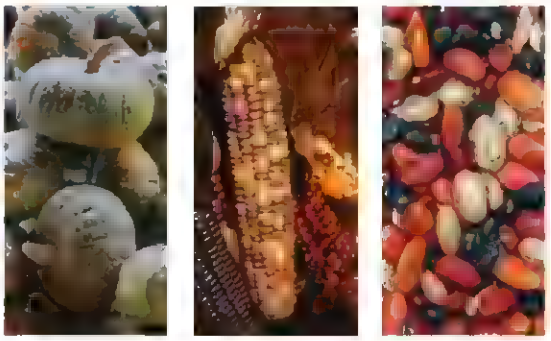


Figure 4

64. Ulcers appear in only one place in the entire digestive tract—the stomach. Ulcers tend not to form in the esophagus, small intestine, or large intestine. Why do ulcers tend to form only in the stomach? (9.4, 9.5) K/U T/I

65. A scientist puts pepsin and trypsin in the same test tube in a neutral water solution of pH 7.0. (9.5) K/U T/I
    (a) How can she make pepsin active without activating trypsin?
    (b) How can she make trypsin active without activating pepsin?
    (c) How can she make both enzymes active at the same time?
    (d) How can she make both enzymes inactive at the same time?

66. A biologist observes that the sodium ion concentration is much greater outside a cell than inside the cell. Yet sodium ions continue to move steadily out of the cell and into the surrounding environment. Which kind of transport is moving sodium ions—active or passive transport? Explain. (9.5) K/U T/I

67. Both vomiting and diarrhea are responses to an infection. Another response that the body makes to a bacterial infection is fever—raising the body temperature How might fever be helpful in combating a bacterial infection? (**Hint**: Bacteria have enzymes, and all enzymes have an optimum operating temperature.) (9.6) T/I A

68. Could life forms on a distant planet develop a metabolic process in which food was broken down to release energy without involving oxygen? Explain your thinking. (10.1) T/I A

69. If you have not eaten all day, is cellular respiration taking place inside your body? Explain. (10.1) T/I A

70. Cellular respiration requires both oxygen and a food source. (10.1) T/I A
    (a) Which of the two is easier for the body to store?
    (b) What evidence can you provide to prove that it is easier to store? (**Hint:** How far can you run without breathing? Without eating?)

71. Olivia claims that oxygen diffuses directly from the blood to the body cells, where it is used for cellular respiration. Gwen claims that there is no direct diffusion of oxygen into cells. Who is right? Explain. (10.1) K/U T/I

72. For use on a dry planet with little oxygen, a space engineer is designing a space suit to increase oxygen intake. The entire suit will act as a respiratory membrane for absorbing oxygen. Is this design likely to be practical? Explain. (10.2) T/I A

73. Julia compares the negative pressure that draws air into the lungs to a balloon expanding as it fills up. Mahmoun compares the negative pressure to pulling up on a bicycle pump to draw in air. Whose comparison is more accurate? Explain your answer. (10.2) T/I A

74. The fittest individuals have the highest VO_2max values. (10.2) T/I
    (a) Who will burn more oxygen in a given period, a person with a high VO_2max or a person with a low VO_2max?
    (b) Who will generate more ATP in a given period, a person with a high VO_2max or a person with a low VO_2max?
    (c) Suppose you analyzed muscle tissue from a trained athlete and an ordinary person. In which tissue would you expect to find more ATP? Explain.

75. A fish has gills that move water in the "wrong" direction so that blood flows in the same direction (not the opposite direction) as the water being moved by the gills. (10.2) K/U T/I A
    (a) Does this fish have countercurrent exchange? Explain.
    (b) Will oxygen diffuse from the water to the blood vessels in this fish? Explain.
    (c) What consequences—if any—will the fish suffer from this unusual arrangement?

76. In fish, the oxygen concentration of the water outside of the gills is greater than the oxygen concentration inside, so oxygen will diffuse with or without countercurrent exchange. If countercurrent exchange is not required for diffusion, why is countercurrent exchange necessary? (10.2) K/U T/I

77. Scientists debate about whether dinosaurs were warm-blooded or cold-blooded. If dinosaurs were warm-blooded, would you expect them to have had hemoglobin in their blood? Or would their blood have been more like that of insects, without hemoglobin? (10.1, 10.3) K/U T/I A

78. Jacques brought bottles of carbonated spring water on his climb of Mt. Vapour, a 3000 m peak, only to find that the bottle tops popped off on the way—something that never occurred on low-altitude treks he has taken. What accounts for the bottle tops popping off? (10.3) K/U T/I A

79. A doctor measures the oxygen content of blood from a patient's veins and finds that the oxygen's partial pressure is over 5 kPa, much higher than the partial pressure of carbon dioxide. (10.3, 11.3, 11.4) K/U T/I A
    (a) Is the patient in any danger? If so, explain what should be done to help the patient. If not, explain why not.
    (b) With a high partial pressure of oxygen in the blood, will oxygen be able to diffuse into the blood when it reaches the lungs?

80. The pH of the blood of a patient with a low red blood cell count is found to be very low. (10.3) K/U T/I A
    (a) What might have caused this acidic condition?
    (b) How can the doctor remedy the condition to raise the pH of the patient's blood?

81. A scientist has the idea of having athletes train in chambers containing a rich concentration of oxygen to improve their performance. (10.3) K/U T/I A
    (a) How likely are the athletes to secrete extra erythropoietin as a result of their training?
    (b) What is likely to happen to the athletes' production of red blood cells?
    (c) Are the athletes likely to perform better or worse as a result of their training? Explain.

82. A pulmonologist's patient is given a breathing test and found to have no problem during the inhalation part of the breathing cycle. However, the patient has trouble relaxing his diaphragm and lung muscles to allow exhalation. What do you suspect is the patient's problem? (10.3) K/U T/I A

83. A medical researcher is looking for a way to increase a mammal's breathing rate without stimulating any nerves in the body directly. (10.3) K/U T/I A
    (a) How might she use blood levels of dissolved gases to modify breathing rate?
    (b) Which dissolved gas should she focus on? Why is this gas a better choice?
    (c) How does the brain detect this change in gas level? What is the brain's response to the change in gas level?
    (d) Describe what the researcher should do to increase the breathing rate by changing a gas level.

84. A medical researcher is looking for a way to increase a mammal's breathing rate without stimulating any nerves or manipulating gas levels in the blood. (10.3) K/U T/I A
    (a) How might she change the properties of the blood to modify breathing rate? (**Hint:** How does pH affect breathing rate?)
    (b) How will the brain interpret this change? What will the brain's response be to the change?
    (c) Describe what the researcher might do to increase the breathing rate using this method.

85. Asthma is on the rise, especially in big cities among inner-city residents. What environmental factor is likely causing this trend? (10.4) T/I

86. A medical student is having difficulty distinguishing asthma from COPD. (10.4) T/I A
    (a) Which symptoms would be the same for patients with each disease?
    (b) What kinds of infection would the doctor be likely to find in patients with each disease?
    (c) If the doctor could get a patient's air passages completely opened, how could she distinguish between the two diseases?

87. Two parents both carry a single defective gene for cystic fibrosis (CF). (10.4) K/U T/I
    (a) Their first child, a daughter, shows no symptoms of CF. Can the daughter be a carrier for CF? Explain.
    (b) When she grows up, should this daughter worry about having children with CF? Explain.
    (c) A second child of the couple, a son, has CF. What can you conclude about the genes that the child has?
    (d) If the son has his own children, are they certain to have CF? Explain.
    (e) If the son has his own children, are they certain to be carriers of the CF gene? Explain.

88. The FLAP protein that is made by the human body is responsible for the inflammation that causes asthma and other afflictions. Why would the human body make a protein that causes harm to itself? Explain. (10.5) T/I

89. An artificial lung system is hooked up to a patient primarily to remove carbon dioxide from her blood. Why should the level of carbon dioxide inside the machine's artificial alveoli be kept low while the machine is functioning? (10.5) T/I A

90. Insects called midges can beat their wings over 1000 times per second. This rate of activity requires enormous amounts of energy, yet these insects do not have hemoglobin in their blood. (11.1, 10.1) K/U T/I A
    (a) How does having hemoglobin help an animal produce more energy?
    (b) Would hemoglobin be likely to help the midge with its energy requirements? Explain.
    (c) How does the midge get enough oxygen to its muscles cells to be able to move at such a rapid rate?

91. A scientist measured blood being pumped to the body cells of an amphibian. He found it to have much lower oxygen content than blood in a similar location in a reptile's system. Assuming that both animals have similar blood composition, what could account for the higher oxygen content in the reptilian system? (**Hint:** How do the hearts of each animal compare?) (11.1) K/U T/I A

92. A friend received a fairly deep cut on her leg in a soccer game. The cut now has pus forming around it. Is the presence of pus a positive sign that the wound is healing correctly or a sign of infection? Why? (11.2)

93. Leah's uncle is about to receive blood serum in the hospital. Leah is afraid that her uncle could have an adverse reaction if the serum is not an exact match. Should Leah worry? Explain. (11.2) T/I A

94. Doris, who has high blood pressure, has been told by her doctor to avoid having a lot of sodium in her diet. Doris does not understand how increased sodium could increase the pressure of her blood—since she only has so much blood in her body. How would you explain the connection between salt (sodium) and blood pressure to Doris? (11.2) K/U C A

95. You have been running on a hot day and feel overheated. Your nervous system senses your condition and sends out a signal to cool your body down. (11.3) K/U T/I A
    (a) What is the target of the signal?
    (b) What is the response of the target?
    (c) How does this response help cool the body?
96. Why is it a bad idea to exercise right after you have eaten a large meal? (**Hint:** After eating, how is blood in the body redistributed?) (11.3) T/I A
97. A scientist is looking to take measurements in the part of the body that has the lowest blood pressure. Where should she take her measurement? Why is the pressure so low at this location? (11.3) K/U T/I

Evaluation

98. Wendy is a 28-year-old woman who weighs 56 kg and is 168 cm in height. (9.1) T/I A
    (a) According to the Harris–Benedict formula, what is Wendy's basal metabolic rate, or BMR?
    (b) Wendy exercises three times a week at her 1-hour dance–exercise class. Using this activity factor, what is Wendy's average daily energy requirement? (See Table 1, page 399.)
    (c) Wendy consumes about 1800 Cal each day. If 1 Cal is equal to 4.18 kJ, is Wendy consuming about the right amount each day? Explain.
    (d) Suppose Wendy takes up cycling and rides for 1 hour each day. Cycling requires 25.8 kJ per kilogram of body weight per hour. How many extra kCal should she consume with this activity level?
    (e) Two doughnuts have a total of 600 Cal. Does Wendy's cycling make up for the extra energy that two doughnuts provide? Explain.
99. Doug has a problem of overdoing a good thing. For example, when Doug learned that it was good for him, he decided to take more than a daily dose of omega-3 fatty acids each day. Similarly, Doug takes three times as much vitamin C every day as is recommended. (**Important note**: This is a hypothetical situation—do not do what Doug does!) (9.2) K/U T/I A
    (a) Is Doug doing something that may be harmful to his body? Explain.
    (b) Doug claims that if he takes too much of a substance, it will simply be eliminated in his urine. Is this true for either omega-3 fatty acids or vitamin C? Explain.
    (c) Which of the two substances poses a greater threat to Doug's health?
100. Eating can seem risky if you have an upset stomach or a slight case of the flu. Why is it a good idea to avoid foods that are high in fat when your stomach is upset? (9.4) K/U T/I A
101. Analyze the nutrition label in **Figure 5** and answer the following questions.

Figure 5 A nutrition label

    (a) What is the total mass of this package of food?
    (b) Which category of nutrient is predominant in this food?
    (c) Identify two positive aspects and two negative aspects of this food.
    (d) Evaluate the food and make a recommendation about the amount of this food that should be eaten each day.
    (e) Do you think this food is a good choice for a healthy diet? Explain your answer. (9.2) K/U T/I A
102. In high-endurance sports such as cycling, athletes often resort to what is called "blood doping." Blood doping involves an athlete creating extra red blood cells during training sessions, collecting and concentrating them, and freezing them. When the competition date nears, the cells are unfrozen and transfused into the athlete's body. (10.3) T/I A
    (a) What advantage might blood doping give an athlete?
    (b) Do you think that blood doping is a form of cheating?
    (c) In your opinion, how does blood doping compare to other forms of performance enhancement, such as use of anabolic steroids?

103. A faulty engine in a spaceship has leaked carbon monoxide into the cabin. The captain of the ship does not see this as a serious problem for respiration. He will simply add extra oxygen to the cabin to drown out the effects of carbon monoxide. Is this approach likely to work? Explain why or why not. (10.4) K/U T/I A

104. Jemma readily admits that smoking is bad for you in almost every way. However, when evaluating the damage from carbon monoxide in smoking, she sees little to be concerned about. Do you agree with Jemma's assessment? Explain. (10.4) K/U T/I A

105. On the phone, Owen was told by his doctor that he had "high cholesterol" but that he should not worry about it. The call was interrupted before he could find out exactly what the doctor meant. (11.5) K/U T/I A
    (a) What two things could the doctor mean when she said Owen had high cholesterol?
    (b) What do you think the doctor most likely meant when she said Owen had high cholesterol?
    (c) What special steps should Owen take to be safe in this situation?

Reflect on Your Learning

106. Quickly review and think about what you learned in the first two sections of Chapter 9. T/I C A
    (a) How has your understanding and appreciation of the importance of an appropriate diet and an active lifestyle changed as a result of your learning?
    (b) In which areas of your diet and physical activity do you think you can improve? Write a letter to yourself in which you set reasonable, achievable goals for improvement. Seal the letter in an envelope and ask a parent or a good friend to give it back to you at an identified future date.
    (c) What are the potential obstacles to attaining your goals? How do you plan to overcome these obstacles?

107. You have likely heard that smoking is bad for you since you were a young child. However, you may have gathered new information in this unit about the dangers of smoking. Describe how going through this unit gave you new insight on the dangers of smoking. K/U T/I A

108. Suppose you found out that you were a carrier for the defective gene for cystic fibrosis. T/I A
    (a) What things in your life would change, if any? What plans would change?
    (b) Do you think it is important to have this information, or would you rather not know? Explain your thinking.

109. Do you know your blood type? If you do not, consult your parents or doctor to learn what it is. To which members of your family could you donate blood? To which members could you not donate blood? T/I A

110. Risk factors for coronary artery disease, or CAD, include smoking, high blood pressure, being overweight, high LDL cholesterol, age, physical inactivity, sex, and genetic makeup. Which of these risk factors do you currently have or are likely to develop? What steps can you take to minimize your risk of CAD? T/I A

Research

GO TO NELSON SCIENCE

111. Low-carbohydrate diets such as the South Beach Diet or Atkins diet have gained much attention in recent years. Use the Internet and other sources to research the success of these diets in both controlling weight and affecting blood levels of HDL and LDL cholesterol. Report your findings in a short newspaper-style editorial. T/I C

112. Digestive enzymes such as pepsin that break down food proteins are themselves proteins. What prevents pepsin from breaking down other pepsin molecules and therefore destroying itself? Use the Internet and other sources to research this topic and provide the solution in the form of a science question and answer forum. T/I C

113. Many people think that smoking cigars is not as harmful as smoking cigarettes because cigar smoke is not inhaled. Use the Internet and other sources to investigate this idea. Write a short paragraph on your conclusions. T/I C A

114. What is the connection between stress and CAD? Use the Internet and other sources to research this topic. Prepare a PowerPoint-style presentation on your findings. T/I C A

UNIT 5

Plants: Anatomy, Growth, and Function

OVERALL EXPECTATIONS

- evaluate the importance of sustainable use of plants to Canadian society and other cultures
- investigate the structures and functions of plant tissues, and factors affecting plant growth
- demonstrate an understanding of the diversity of vascular plants, including their structures, internal transport systems, and role in maintaining biodiversity

BIG IDEAS

- Plants have specialized structures with distinct functions that enable them to respond and adapt to their environment.
- Plant variety is critical to the sustainability of ecosystems.

UNIT TASK PREVIEW

As you progress through this unit, you will read about the importance of plants to society and to human populations. You will also explore how humans use plants as a resource. For the Unit Task, you will choose one plant that has made a significant impact on human society and research how it is grown and used. You will also discuss how we might grow and use this plant in a more sustainable way.

The Unit Task is described in detail on page 630. As you work through the unit look for Unit Task Bookmarks to see how information in the section relates to the Unit Task.

FOCUS ON **STSE**

WAKING UP TO COFFEE

Many of us start our day with a cup of coffee. Coffee is the second most valuable traded commodity on Earth, next to petroleum. Coffee helps the world get to work in more than one way!

Coffee "beans" are not really beans. Rather, they are the seeds found in the berries of the coffee plant; the berries turn red as they ripen. Coffee berries are harvested from two coffee plant species, both native to Africa. Coffee plants are evergreen shrubs or small trees that grow in shaded areas. Traditionally, coffee producers have planted coffee plants among the other trees of the rainforest, which, in turn, provide shade for the coffee plants. The demand for coffee has grown, and coffee is now cultivated in over 70 tropical and subtropical countries, including many Central and South American countries.

The high demand has changed the way coffee is grown. For efficiency, land was cleared and coffee plants were grown in full sunshine on plantations. Clearing the land negatively affected plant and animal species that relied on the natural forest, including some songbirds that migrate from North America. These include orioles, warblers, thrushes, and vireos. These birds spend the winter in Central and South America. Clearing the land for coffee plantations reduces their winter habitat.

Coffee plantations have other ecological consequences. The plantations are monocultures, so they lack diversity and are more susceptible to disease and pests than the natural rainforest is. Growers therefore use insecticides, fungicides, and herbicides. Plantations must also be irrigated, since there is no shade to reduce evaporation of water from the soil. Since agricultural chemicals and irrigation can damage the natural environment, coffee plantations are not environmentally sustainable.

As consumers learned more about the environmental damage coffee production has caused, methods of coffee production slowly began to change. You may have seen "organic shade-grown" labels on coffee packages in your local coffee shop. Organic shade-grown coffee is grown on smaller farms and farm co-operatives without the use of chemical fertilizers. Either existing rainforest trees shade the coffee plants, or fast-growing shade trees are planted. This helps prevent soil erosion and water pollution and maintains habitat for songbirds. Interestingly, most people think shade-grown coffee tastes better than plantation-grown coffee. However, there is a downside. Producing coffee this way is much more labour intensive and the yields are lower, so shade-grown coffee costs considerably more than plantation-grown coffee. As with many issues involving sustainability and the environment, economics always plays a role. As individual consumers, we have to decide how to balance price with environmental concerns.

Questions

1. Coffee drinking is also associated with long lineups at drive-throughs and with disposable cups. How do these factors influence the environmental impacts of coffee consumption?
2. Should all coffee shops be made to offer organic shade-grown coffee? Explain your rationale.
3. Create a graphic organizer with the word "sustainability" at the centre. Fill in the graphic organizer using the information about coffee production above.

UNIT 5 ARE YOU READY?

CONCEPTS

- describe the process of cell division and specialization
- recognize the organization of cells into tissues, organs, and systems
- explain basic plant cell structure
- understand the relationship between photosynthesis and cellular respiration
- recognize the factors that influence ecosystem sustainability, including the activities of humans

SKILLS

- prepare a wet-mount
- use a microscope properly
- draw labelled biological diagrams
- communicate ideas, plans, procedures, results, and conclusions using appropriate language and formats
- analyze and interpret qualitative and/or quantitative data

Concepts Review

1. Match each term on the left with the most appropriate description on the right. K/U

(a) vascular tissue	(i) rigid outermost cell layer found in plants and certain algae, bacteria, and fungi
(b) xylem	(ii) movement of molecules from an area of higher concentration to an area of lower concentration
(c) osmosis	(iii) tissue that carries water and dissolved substances up from the roots
(d) phloem	(iv) movement of water molecules across a selectively permeable membrane
(e) chlorophyll	(v) tissue that transports sugars and other dissolved substances throughout the plant and down to the roots
(f) vacuole	(vi) conductive tissue that transports water and dissolved substances
(g) cell wall	(vii) pigment that captures energy from sunlight for photosynthesis
(h) diffusion	(viii) large, fluid-filled compartment in plant cell

2. Describe the location and role of stomata in plants. K/U
3. Photosynthesis and cellular respiration have been called complementary processes. K/U T/I A
   (a) Write the word equation for photosynthesis and the word equation for cellular respiration.
   (b) Explain why photosynthesis and cellular respiration are said to be complementary processes.
   (c) Based on your answer for (a), predict what would happen if there was less photosynthesis globally.
4. (a) Compare the two images in **Figure 1**. Based on what you see in the photographs, predict which farm has more biodiversity.
   (b) Which of the two farms in Figure 1 is more sustainable? Explain why. T/I A

Figure 1

5. (a) What is the function of meristematic tissue?
   (b) What other process is needed for a cell to become specialized (e.g., to become an epidermal cell)? K/U
6. Do plants have organs and organ systems? Explain your reasoning. K/U

7. Identify the structures shown in **Figure 2**. K/U

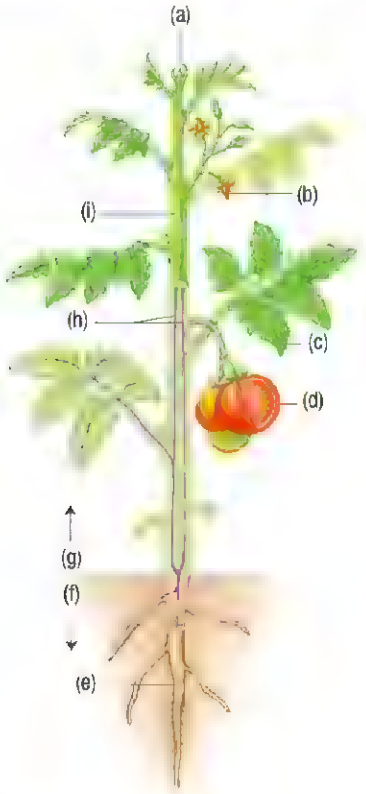


Figure 2 Basic plant body

8. In what cell organelle does photosynthesis occur? K/U
9. Through photosynthesis, plants are the ultimate food source for almost all terrestrial life on Earth. K/U A
   (a) How is this process linked to maintaining Earth's climate conditions?
   (b) What human activities have the greatest impact on native plant populations and diversity?
   (c) Which human activities negatively affect the role of plants in maintaining Earth's climate? Explain your reasoning.
10. Earth's biomes have different climates, soils, and plant types. T/I
    (a) Predict the adaptations you would expect to see in plants that grow in the following locations.
       (i) the Arctic
       (ii) hot desert
       (iii) tropical rainforest
    (b) Explain the predictions you made in (a).
11. A nursery worker reproduces many of her plants by rooting cuttings. What kind of reproduction is this? K/U
12. Plants undergo photosynthesis and cellular respiration. Both processes require that plant cells exchange gases with the atmosphere. What leaf structure is responsible for gas exchange in plants? K/U
13. Predict the adaptations of plants growing in a region of your own choosing. In your answer, describe the conditions to which the plant would be adapted. K/U A

Skills Review

14. **Figure 3** is a photograph of parenchyma cells in the root of a buttercup.

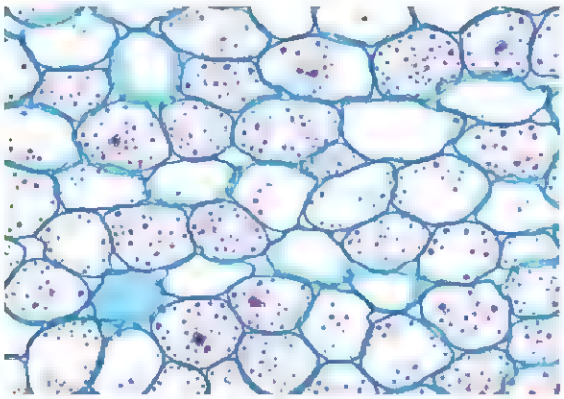


Figure 3 Light microscope image of a buttercup (*Ranunculus*) plant root (×80)

   (a) Draw a labelled biological diagram of three adjacent parenchyma cells. K/U C
   (b) When this sample was prepared for viewing under the microscope, iodine stain was applied. Iodine stains starch. Based on this information, what is one function of the parenchyma cells in this root? K/U T/I C
   (c) What characteristic(s) of these cells allows you to identify them as plant cells rather than animal cells? K/U T/I
15. Create a graphic or written description of the steps in preparing a wet-mount slide for viewing under a microscope. T/I C A

CAREER PATHWAYS PREVIEW

Throughout this unit you will see Career Links in the margins. These links mention careers that are relevant to plant anatomy, growth, and function. On the Chapter Summary page at the end of each chapter you will find a Career Pathways feature that shows you the educational requirements of the careers. There are also some career-related questions for you to research.

CHAPTER 12

The Importance of Plants

KEY CONCEPTS

After completing this chapter you will be able to

- evaluate the importance of plants to the Canadian society
- identify and draw biological diagrams of specialized tissues in roots, stems, and leaves
- compare and contrast monocot and eudicot plant structures and evolutionary processes
- describe the structures of the various types of tissue in vascular plant structures
- explain the mechanisms by which plants transport and distribute materials within the plant body

Why Are Plants So Useful?

If you were asked to describe how we use plants, what would you say? Most of us would talk about using plants for things such as food, construction material, medicines, and clothing. What about using plants to create music? For example, the acoustic guitar is a popular instrument. The sound of a particular acoustic guitar depends in part on the characteristics of the wood used to build it. The wood must have very strong fibres and no knots. Not all tree species can produce wood with these characteristics. Wood for guitars usually comes from alder, beech, maple, mahogany, or walnut trees.

The fact that a guitar maker has a choice of woods with different characteristics is one reason why plants are so useful—there are so many different kinds. Each of the roughly 270 000 known species has a unique set of adaptations. The plant kingdom therefore has an incredibly wide variety of structures, fibres, and chemicals.

In this chapter you will discover how plants touch almost every part of human society. This makes plants big business. According to Statistics Canada, in 2006 the canola crop was worth $2.5 billion, the wheat crop was worth $1.8 billion, and the corn crop was worth $753 million. These amounts are no small potatoes (and the potato crop, incidentally, brought in $899 million)! Many industries also depend on plant products, such as the textile, furniture, and pharmaceutical industries.

Plants have a far greater role than meeting human needs. Plants are the foundation of almost all terrestrial food webs. They create habitat for other organisms and are pivotal in maintaining the health of Earth's atmosphere, water, and soil. It is therefore vital that we use plants in a sustainable way to meet our needs.

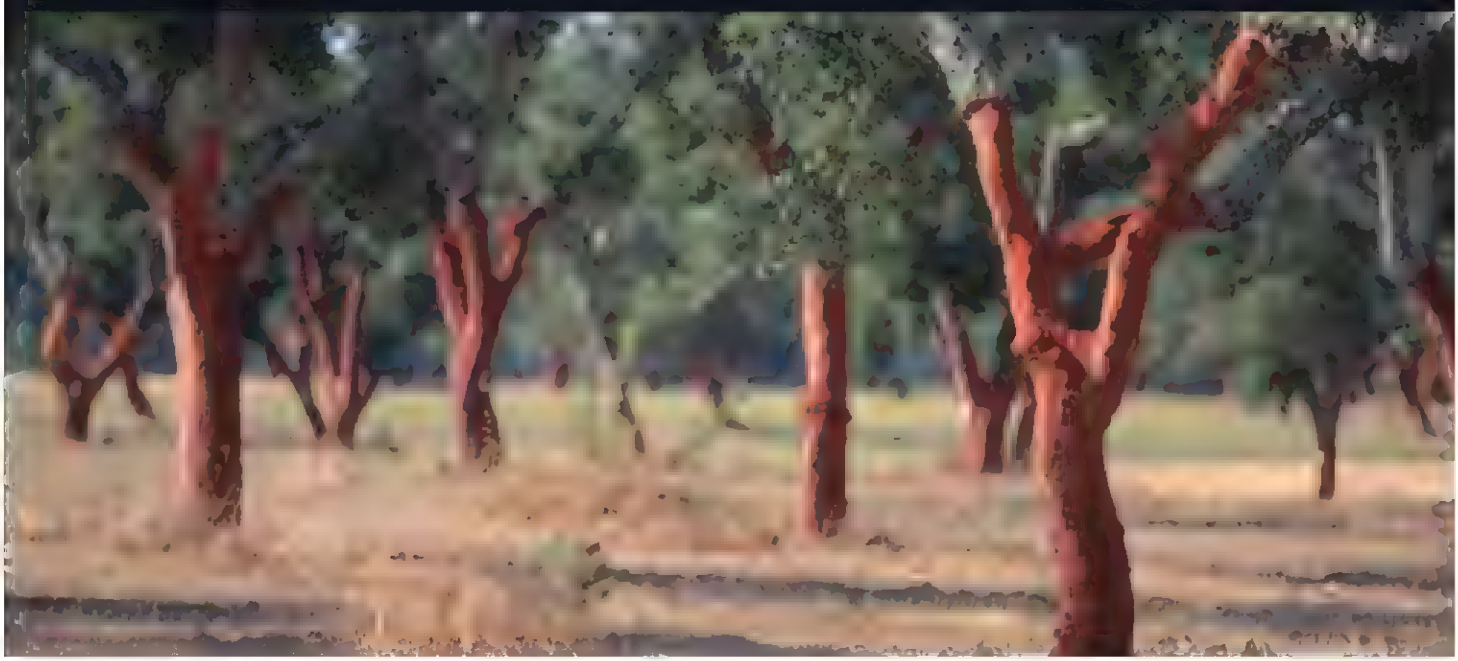
Cork is an example of a plant product produced in a sustainable way. Cork products, such as flooring, are made from the bark of the cork oak tree. Cork forests are found in Spain and Portugal and are home to rare bird and animal species such as the black stork and Iberian lynx. Instead of cutting down an entire tree and stripping off all the usable bark, workers remove a layer of bark cork from part of the trunk. This does not damage the tree or its ecosystem, and the cork bark grows back. More bark can be removed 10 years later. A cork tree managed this way can continue to produce cork for most of its 200 year life span. Many communities are built around growing and harvesting cork.

In this chapter you will explore some of the many ways in which plants support human society and how these uses can be more environmentally sustainable. You will also find out about the anatomy of the plant body and how its organs work. You will also learn how the plant transports materials within its body.

STARTING POINTS

Answer the following questions using your current knowledge. You will have a chance to revisit these questions later, applying concepts and skills from the chapter.

1. In what ways do you think leaves are important to plants, humans, and ecosystems?
2. Explain how plant roots are important to
   (a) the plant
   (b) our economy
3. Other than for wood, how do humans use stems?
4. What plant structures do you think are of
   (a) most importance to a plant's survival
   (b) greatest value to humans
   (c) highest significance to the environment
5. Predict the process by which water enters a plant cell. How do you think water is transported within the plant?



Mini Investigation

Potato Plastic!

Skills: Researching, Predicting, Planning, Performing, Observing, Analyzing

SKILLS HANDBOOK A2.1

Plants have many uses. They provide us with food, wood and paper products, fibres, fuels, and medicines. Plant-based products have a number of advantages over products made from synthetic materials. They are biodegradable and can potentially be grown in an environmentally friendly and sustainable way. In contrast, synthetic materials, such as plastics produced from non-renewable resources, are non-biodegradable, may release toxins, and are not environmentally friendly. What if plastics could be made from plants?

In this investigation you will make a plant-based plastic substitute.

Equipment and Materials: 250 mL beaker; stirring rod; hot plate; beaker tongs; glass plate or tile; 10 mL potato starch; 40 mL water; 3 mL vinegar; 3 mL glycerol

1. Put on your eye protection and apron.
2. Add the starch, water, vinegar, and glycerol to the beaker and mix thoroughly.
3. Gently heat the mixture on a hot plate while stirring constantly. The mixture should be hot but should not boil.

Be careful not to touch the hot plate when it is on. Use tongs to handle the hot beaker. When you plug the hot plate into the electrical socket, make sure everything is dry. Unplug the hot plate by pulling the plug, not the cord

4. Continue to gently heat and stir the mixture until it becomes clear and starts to form a thick, sticky gel.
5. Once the mixture has formed a thick gel, use tongs to remove the beaker from the hot plate.
6. Pour the mixture onto a smooth, flat surface such as a glass plate or tile. Spread out the mixture to a thin film.
7. Allow the gel to dry for several days at room temperature.
8. Remove and examine the "bioplastic" film.

A. Describe the properties of your bioplastic. How does it compare to other plastic materials in terms of flexibility, transparency, strength, and ductility? T/I A

B. Suggest possible applications/uses for your bioplastic. T/I A

C. Do you think this bioplastic could be recycled? Do you think it is biodegradable? Do you think it is flammable? T/I A

D. Design a procedure to test one of your predictions. Obtain your teacher's approval if you wish to conduct your test. SC SC SC

E. Use the Internet and other sources to find out more about bioplastics research and development in Canada. What products are scientists hoping to develop? What makes the potato a good choice for such research and development in Canada? T/I A

GO TO NELSON SCIENCE

12.1 The Characteristics of Plants

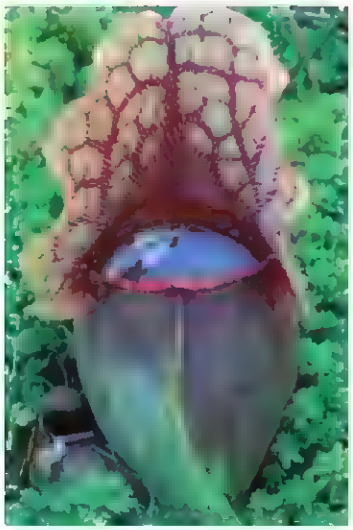


Figure 1 The cup-like structure of this pitcher plant contains water and enzymes that d gest any insects that get trapped inside.

carbohydrate a molecule that contains only atoms of carbon, hydrogen, and oxygen in a ratio of 1:2:1

All organisms face changes in their environment. For example, the temperature may change, or it may start to rain. Most organisms are able to move away from conditions that are not suitable. Plants, however, have unusual lives because they are immobile. They cannot move independently from one place to another and are therefore limited to the environment around them to meet their needs.

To cope with their immobility, each plant species has specific adaptations for a particular range of environmental conditions. For example, whereas most plants absorb nutrients from water in the soil, pitcher plants obtain nutrients by digesting other organisms (**Figure 1**). They have adapted this way because the soil in which they grow is very low in nitrogen.

Basic Needs of Plants

Plants need energy, nutrients, water, gas exchange, protection from herbivores and disease, and they need to reproduce. How do plants manage to meet all these needs while staying in one spot?

Plants capture energy from incoming solar radiation and convert it to chemical energy through photosynthesis, a complex process that uses carbon dioxide and water to form glucose and oxygen. The word equation for photosynthesis is

$$\text{carbon dioxide} + \text{water} \xrightarrow{\text{solar energy}} \text{glucose} + \text{oxygen}$$

Glucose is a carbohydrate. A **carbohydrate** is a molecule that consists only of carbon, hydrogen, and oxygen atoms. Carbohydrates are the main source of the chemical energy plants need for maintenance, growth, and development. Through photosynthesis, plants can meet their needs for chemical energy in any environment that has enough light, carbon dioxide, and water. Because light is so important for making carbohydrates, plant species have developed many different adaptations to capture as much light as possible. For example, some plants can adjust the position of their leaves to maximize their exposure to sunlight.

Since they are carbohydrate rich, and therefore energy rich, being eaten is an unfortunate fact of life for many plant species. Plants are a food source for a wide range of organisms. Since they cannot move away from herbivores, plants have developed other ways to protect themselves. Many plants produce toxic or bad-tasting substances to keep herbivores away. Others produce a tough, hairy, or prickly outer layer (**Figure 2**).

Figure 2 (a) Tree bark is an adaptation that protects the plant from herbivores and other damage. (b) Many plants have hairy surfaces that deter insects and other herbivores. (c) Thorns and spikes can also protect a plant from some herbivores.

Plants need specific nutrients, such as nitrogen, phosphorus, and potassium, in order to synthesize the proteins, lipids, and other compounds needed in their cells. Most plants absorb nutrients as dissolved substances in water. As you have learned, most plants are helped in this process by mycorrhizal fungi associated with their roots. Plants also need water for photosynthesis and many other processes, such as the growth and repair of cells. If a plant loses too much water it will wilt and may die; similarly, it may die if it is exposed to too much water.

Plants are living organisms and need to exchange gases with the environment during processes such as photosynthesis and cellular respiration. In vascular plants, most gas exchange happens in the leaves.

Like any organism, plants need to reproduce. They do so through both asexual and sexual reproduction—meaning that male and female gametes, usually from two individuals, have to meet and join. Since individual plants cannot move, plants have evolved some amazing adaptations to ensure that their gametes unite and that the resulting zygote has an appropriate environment in which to germinate and grow. You will explore reproduction in vascular plants in Chapter 13.

The Vascular Plant Body: Roots and Shoots

Even though vascular plants come in an incredible variety of shapes and sizes, the bodies of most vascular plants have the same basic design—they consist of an underground root system and an above-ground shoot system (**Figure 3**). (Some plants, called epiphytes, grow on other plants and live entirely above ground, however.) All cells in the plant body have cell walls composed mainly of cellulose molecules—linked chains of glucose (**Figure 4**).

Figure 4 Onion cells have thick cell walls composed of cellulose.

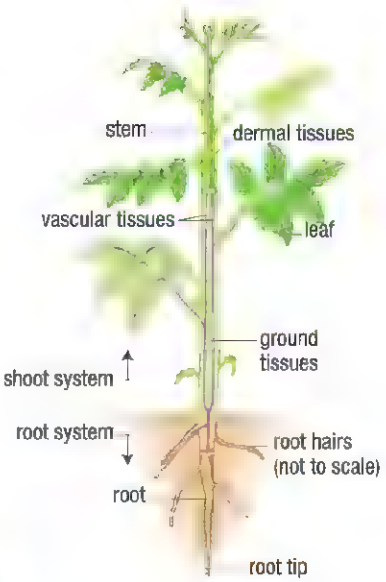


Figure 3 The general structure of a vascular plant. The shoot system includes the stems and leaves. The root system includes all the root material.

Vascular plants have three main non-reproductive organs: the leaf, the stem, and the root. These organs are primarily composed of three tissue types: dermal tissue, vascular tissue, and ground tissue (**Table 1**).

Table 1 Basic Tissue Types in Vascular Plants

Tissue	Description	Role
Dermal tissues	• two tissue types: epidermis and periderm • outermost cell layers • often have thicker cell walls • covered with a waxy cuticle	• protect against injury, herbivores, disease and water loss
Vascular tissues	• two tissue types: xylem and phloem • xylem—thick-walled cells, dead at maturity • phloem—thin-walled cells, living at maturity	• transport water and nutrients • support the plant body
Ground tissues	• three tissue types: • parenchyma—thin-walled cells, living at maturity • collenchyma—thick-walled cells, living at maturity • sclerenchyma—cells with lignin in their cell walls, dead at maturity	• perform cellular processes to support growth and development (parenchyma and collenchyma) • store carbohydrate, especially starch (parenchyma) • support and protect plant body (collenchyma and sclerenchyma)

Vascular plants also contain meristematic tissue. **Meristematic tissue** (also called a **meristem**) is an area of actively dividing undifferentiated cells (meristematic cells). Meristematic cells are found in areas of the plant where growth occurs. They eventually develop into specialized cells and tissues.

meristematic tissue (meristem) tissue consisting of dividing undifferentiated cells (meristematic cells) found in areas of the plant where growth can take place

Updating the Phylogeny of Vascular Plants

Scientists constantly revise and update their theories as new information comes to light. The same is true in plant classification. Recall from the Diversity of Living Things unit (Unit 1) that there are three major groups of vascular plants: the lycophytes and pteridophytes (club mosses; ferns and their relatives), the gymnosperms (conifers), and the angiosperms (flowering plants). **Figure 5** outlines how these groups of vascular plants can be distinguished by key evolved traits.

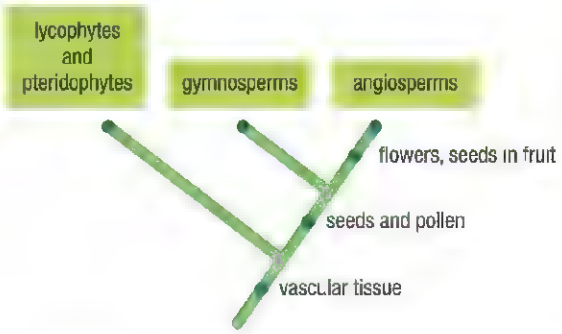


Figure 5 Evolutionary relationships of the three groups of vascular plants

cotyledon a structure in the seeds of flowering plants (angiosperm) that stores and supplies nutrients to the embryo

WEB LINK

Angiosperms can be classified into many groups, depending on the number of characteristics that are compared. To learn more about how angiosperms can be classified,

GO TO NELSON SCIENCE

The seeds of angiosperm species may contain either one or two **cotyledons**, which are structures that supply nutrients to the plant embryo. Until recently, angiosperms were divided into only two groups: monocots, which have one cotyledon, and dicots, which have two cotyledons. However, recent DNA studies suggest that placing all dicot species into one group does not reflect the evolutionary relationships among these species. Dicots now fall into at least four groups: Amborellales (a group with one surviving species, *Amborella tricopoda*), Nymphaeales (water lilies), other early angiosperms, and eudicots ("true dicots"). Scientists think that Amborellales, water lilies, and the other early angiosperms evolved before monocots and eudicots (**Figure 6**). Monocots evolved most recently, about 100 million years ago.

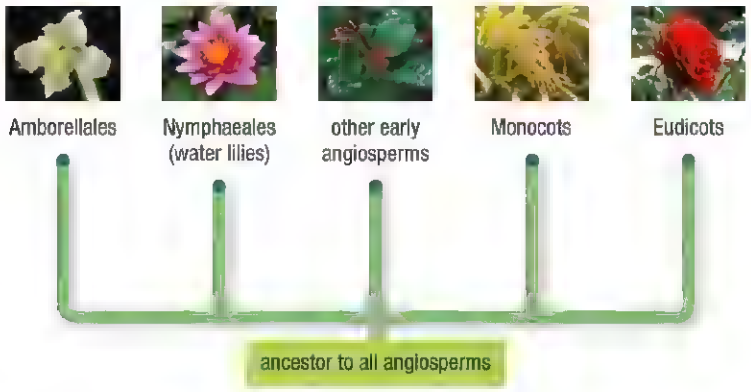


Figure 6 Evolutionary relationships among angiosperms

Monocots and eudicots are both very successful groups. Roughly one-quarter of all angiosperm species are monocots and more than two thirds of angiosperms are eudicots. They are found in every environment that supports plant life and often live side by side in the same habitat. For example, a lawn of grasses (monocot plants) will often contain eudicots such as dandelions and clover.

Monocots and eudicots are vitally important to sustaining human life and supply most of our food, fibre, and building materials (**Figure 7**).

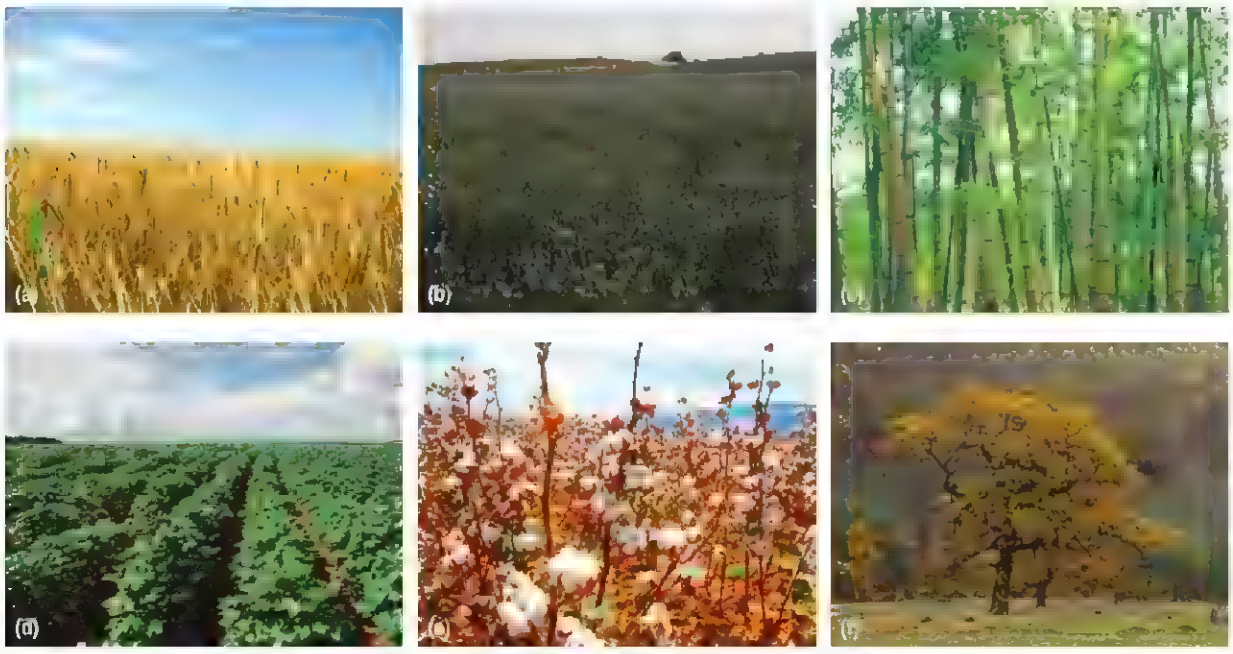


Figure 7 (a) Wheat, (b) flax, and (c) bamboo are monocot species that can be used for food, fibre, and building materials, respectively. (d) Soybeans, (e) cotton, and (f) oak are eudicots that can also be used for these purposes.

12.1 Summary

- Plants have adaptations to help them make food, exchange gases, obtain nutrients, defend themselves, and reproduce, even though they cannot move independently.
- The body plan of most vascular plants includes leaves, stems, and roots.
- Vascular plants include club mosses, ferns and their relatives, gymnosperms, and angiosperms.
- Angiosperms may be classified as Amborellales, water lilies, other early angiosperms, monocots, and eudicots.

12.1 Questions

1. Plants are unique in part because they are immobile. What other aspect of plants makes them unique? K/U
2. When we eat a balanced diet, all our nutritional needs are met. Compare and contrast this with how a plant meets all its nutritional needs. K/U A
3. Why do plants need to exchange gases with the environment? K/U
4. (a) Which two tissue types make up plant vascular tissues? What role(s) do these tissues play in the life of a plant?
   (b) Which type of tissue would you expect to be most commonly used as a food source? Why?
   (c) Which types of tissue play a protective role in the plant?
   (d) How are meristematic tissues uniquely different from all other tissue types? Where can meristematic tissues be found in a plant? K/U T/I A
5. Outline how scientists have changed the way they classify angiosperms. K/U
6. Which angiosperm groups are most useful to humans? Explain why. K/U
7. Suppose a robin and an oak tree share the same environment. One summer day is particularly hot and dry. Compare the ability of these two organisms to respond to this change in environmental conditions. K/U A
8. How might the fact that plants do not move influence their ability to adapt to climate change and other environmental changes? T/I

12.2 Leaves

Perhaps the most popular leaf in the world comes from the plant *Camellia sinensis*. The Chinese were the first to use the leaves of the *Camellia* to make tea, about 5000 years ago. From there, tea-drinking spread through Southeast Asia and Japan. Europeans were introduced to tea when they arrived in China in the seventeenth century, and today tea is consumed around the world.

Tea has had a profound effect on many cultures. Japan and China have elaborate ceremonies developed around the drinking of tea (**Figure 1**). The popularity and relative scarcity of tea made it a very valuable commodity, so at first drinking tea was an upper class privilege. Trading in tea then became big business. China was the main producer, and trade routes were established to western Europe and Russia. These trade routes also allowed cultural exchange between Europe and Asia. Tea was thought to have medicinal properties and so became more popular among Europeans. By the late 1600s, tea drinking was common worldwide.

Figure 1 A Japanese tea ceremony.

UNIT TASK BOOKMARK

As you work on your Unit Task, consider how the demand for particular plant products, such as tea leaves, by wealthier nations can affect human life and the environment in less wealthy areas.

Research This

Sustainable Tea Production

Skills: Researching, Analyzing, Identifying Alternatives, Defending a Decision

SKILLS HANDBOOK A5.1

Tea is usually produced in large plantations, where it is the only plant grown (**Figure 2**). It is often grown in less-developed nations and harvested by workers who receive low pay and few benefits. This situation is beginning to change, however. Tea growers are developing new ways of growing and harvesting tea leaves that provide the workers with larger incomes and have fewer negative effects on the environment.

1. Use the Internet and other sources to research sustainable tea production.

A. Why are traditional ways of growing and harvesting tea not sustainable? T/I A

B. What changes are taking place in the tea industry to make it more sustainable? T/I A

C. Is there a link between improved living and working conditions for workers and sustainable production of tea? Explain. T/I A

Figure 2 Many different varieties of tea made from *Camellia* are now produced in China, India, Sri Lanka, Taiwan, Sumatra, Indonesia, and parts of Africa including Kenya.

GO TO NELSON SCIENCE

Functions of Leaves

Tea plants contain many chemical compounds, including pigments, tannins, and caffeine. These compounds help the leaves function. For example, both tannins and caffeine are noxious defence chemicals that protect the leaves from herbivores. Leaves may play various roles in the plant, including photosynthesis, gas exchange, storage, and protection from predators

Leaves are the primary site of photosynthesis in most plant species. Recall that during photosynthesis, plant cells use solar energy to convert carbon dioxide and water to glucose and oxygen. The plant uses the glucose as a building material. Plants also use glucose as an energy source for cellular processes. Humans and many other organisms rely on the oxygen released by photosynthesis to breathe. Recall that carbon dioxide is a greenhouse gas that contributes to climate change. On a global scale, therefore, photosynthesis has an important influence on the climate, since it removes carbon dioxide from the atmosphere.

Leaf cells absorb energy from sunlight in an organelle called a **chloroplast** (**Figure 3**). Certain cells in leaves each contain many chloroplasts. Each chloroplast contains various **photopigments**, which are chemicals that absorb particular wavelengths of light. The most common photopigments are the chlorophylls, which absorb light at the red and blue ends of the visible light spectrum and reflect green light. This gives leaves their characteristic green colour. Chloroplasts also contain accessory pigments, which are pigments that absorb light wavelengths not absorbed by chlorophyll.

chloroplast an organelle found in large numbers in many p ant cells; the site of photosynthesis within a plant cell

photopigment a pigment that undergoes a physical or chemical change in the presence of light

Another function of leaves for most species is gas exchange between the interior of the plant and its environment. The surface (epidermis) of most plants' leaves contains many pores through which gases pass in and out. Two important cellular processes require gas exchange: photosynthesis and cellular respiration. Photosynthesis uses carbon dioxide gas and releases oxygen gas and water vapour; cellular respiration uses oxygen and produces carbon dioxide.

Leaves may also offer protection from herbivores. In some species such as cacti, leaves are reduced to sharp spines that help protect the thick, green photosynthetic stem. Other leaves protect themselves with surface hairs, which make the leaves unpalatable, and may contain irritating compounds. Other species produce toxins or bad-tasting chemicals within their leaves to deter herbivores.

Figure 3 The small green dots in these *Elodea* (pondweed) cells are the chloroplasts.

Structure of Leaves

The general structure of a leaf helps it carry out its roles in photosynthesis and gas exchange. As shown in **Figure 4**, most leaves have a flattened area, known as a **blade**. The blade is attached to the stem by a stalk-like structure called a **petiole**. Leaves can be simple, with just one blade, or compound, with several leaflets attached to the petiole.

blade the flat part of a leaf

petiole the stalk that attaches the leaf blade to the plant stem

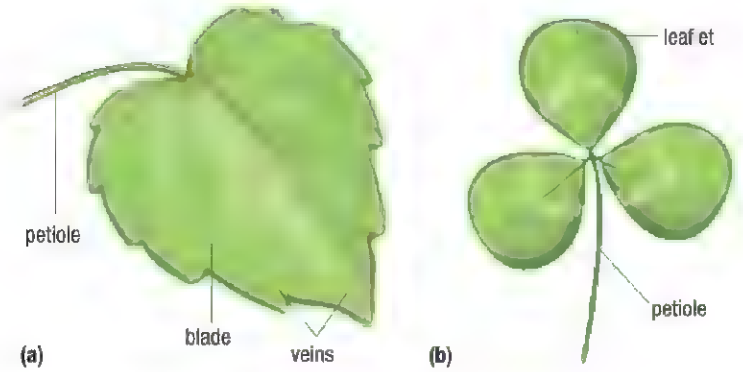


Figure 4 (a) A simple leaf and (b) a compound leaf

venation the arrangement of veins with n a leaf

The veins of leaves contain the vascular tissue. The arrangement of the veins within a leaf is called its **venation**. Monocots and eudicots have distinct venation. Monocots have parallel venation; the veins are parallel to one another (**Figure 5(a)**). Eudicots have branching venation: the veins form a branching network (**Figure 5(b)**).

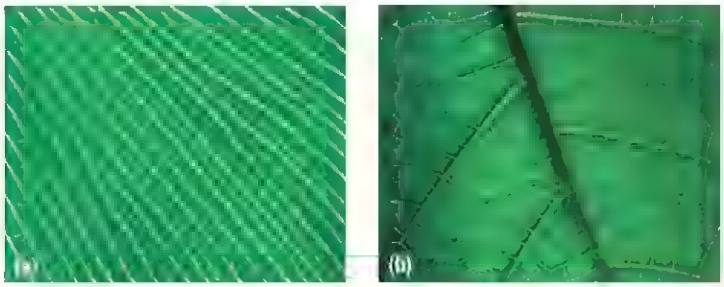


Figure 5 (a) This monocot leaf has veins running parallel to each other. (b) This eudicot leaf has a network of veins.

LEARNING TIP

Leaf Shape

Most familiar leaves are flat and very thin with a distinct upper and lower surface. This shape maximizes the efficiency of the leaves in capturing sunlight and ensures that they are very lightweight and easy to support. Other factors, such as environmental conditions and the need to conserve and/or store water, have resulted in some plants evolving other specialized leaf shapes.

Internal Leaf Structure

The cells in a leaf are arranged to support photosynthesis and gas exchange. **Figure 6** shows the internal structure of a leaf in a typical vascular plant.

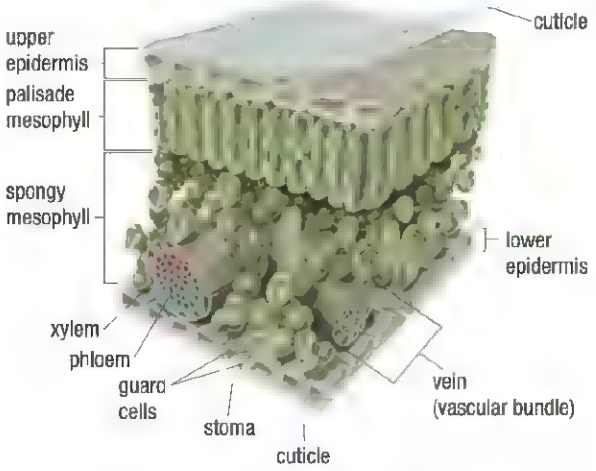


Figure 6 General internal leaf structure of vascular plants

mesophyll the photosynthetic middle layer of cells in the leaf of a terrestrial p ant

palisade mesophyll the ayer of elongated photosynthetic cells arranged in columns under the upper surface of a leaf on a terrestrial plant; part of the mesophyll

spongy mesophyll the layer of loosely packed photosynthetic cells with large air spaces between them under the lower surface of a leaf on a terrestrial plant; part of the mesophyll

stoma opening in eaves through which gases pass in and out of the leaves; also called stomate

guard cell one of two kidney shaped cells that control the opening and closing of a stoma

The epidermal cells are tightly packed in a single layer and covered by a waxy coating called the cuticle. The cuticle prevents water loss and provides a physical barrier against bacteria, moulds, and insects. Epidermal cells do not contain chloroplasts, so they do not perform photosynthesis. Epidermal cells are transparent, so light can pass through them to the cells within the leaf.

Chloroplasts are found mainly in the cells of the **mesophyll**, which means "middle leaf." This ground tissue is specialized for photosynthesis. In most terrestrial plants there are two parts to the mesophyll. The region directly under the upper epidermis is the **palisade mesophyll**. Cells in the palisade layer are elongated and closely packed, and contain many chloroplasts. This arrangement maximizes the amount of light the plant can collect and use for photosynthesis. Directly beneath the palisade is the **spongy mesophyll**, a layer in which mesophyll cells are loosely packed. This layer has large air spaces, which allow for gas exchange between the mesophyll cells and the atmosphere through stomata. A **stoma** (plural: stomata) is an opening in the epidermis of a leaf, through which gases pass in and out. Two kidney-shaped cells, called **guard cells**, control the opening and closing of a stoma. In terrestrial plants, most of the stomata are in the lower epidermal layer, below the spongy mesophyll. The vascular tissues (xylem and phloem) are arranged into veins that run through the spongy mesophyll.

Investigation 12.2.1

Leaf Structure in Vascular Plants (page 575)

Now that you have read about the structure of leaves, you can complete Investigation 12.2.1.

In this observational study you will observe prepared slides of cross-sections of leaves from different vascular plants.

In aquatic vascular plants, such as water lilies (**Figure 7**), the spongy mesophyll is replaced with aerenchyma. **Aerenchyma** is a type of tissue found in aquatic plants that is composed of loosely packed parenchyma cells with large pores between them. Aerenchyma helps leaves to float on the surface of the water. The leaves of many floating aquatic plants have most of their stomata on the upper epidermis, so they are exposed to the air. Other aquatic leaves do not float and have no stomata.

Figure 7 Aquatic plants, such as water lilies, have stomata on the upper surface of the leaf to allow for gas exchange with the atmosphere.

aerenchyma tissue composed of loosely packed parenchyma cells with large pores; found in aquatic plants

Leaf Specializations

The primary role of some leaves is to carry out photosynthesis and gas exchange. However, some leaves also have an important role in protecting the plant, while still others are responsible for storing carbohydrates and/or water. The leaf structure of some species is significantly adapted to performing these functions. **Figure 8** shows some examples of leaves that are specialized for storage.

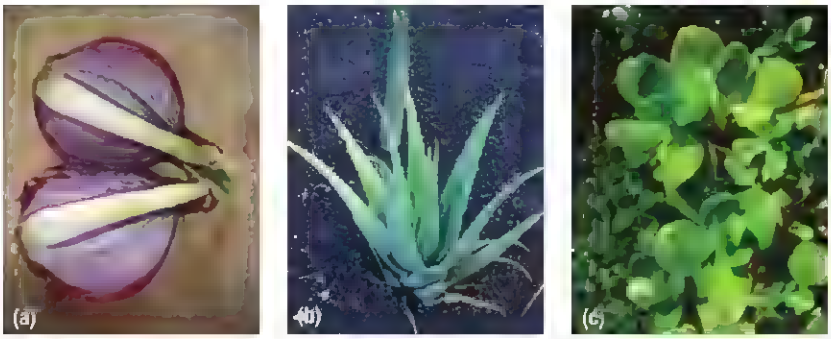


Figure 8 (a) An onion bulb is made up of leaves modified to store water and carbohydrates. (b) *Aloe vera* leaves store water and contain chemicals that have medicinal properties (c) The jade plant is adapted to very dry climates with fleshy leaves that store water.

Plant leaves often have specializations that help protect the plant. Most species produce chemicals in their leaves to repel herbivores. For example, the chemical nicotine, produced by the leaves of tobacco plants, deters herbivores (**Figure 9(a)**). Other species deter herbivores through the structural specializations of the leaves. Cactus spines are modified leaves that no longer perform photosynthesis—instead, their sole function is to protect the stem from being eaten.

Leaf cells contain water, and if the water freezes into ice crystals, the leaf cells can be damaged or killed. In regions that experience below-freezing temperatures, such as Canada, large, thin leaves are easily frozen and killed. Plants with leaves like these lose their leaves in the fall in order to help the plant conserve water and nutrients during the winter (**Figure 9(b)**). In contrast, most gymnosperms do not lose their leaves. To prevent water loss, their leaves are small and have a thick cuticle and epidermis, and the stomata are recessed below the epidermis. Many gymnosperm leaves also produce chemicals that prevent their cells from freezing. Conifer species, such as spruce and pine, have needle-shaped leaves that allow them to shed snow more readily (**Figure 9(c)**).

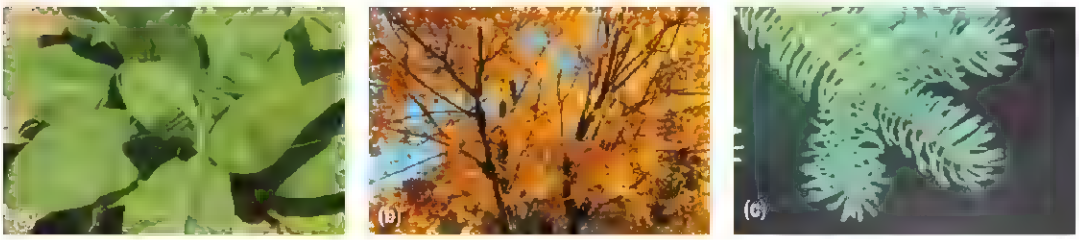


Figure 9 Leaf specializations that protect the plant include (a) deterrant chemicals, (b) the ability to drop leaves, and (c) needle-like leaves with thick cuticles and "antifreeze" chemicals.

Human Uses of Leaves

Leaves provide important nutrients and food energy in the diets of humans and our livestock. Most cultures use fragrant leaves to add flavour to other food. These are known as herbs and include parsley, basil, sage, oregano, and cilantro. Teas can be made from the leaves of many plant species, such as peppermint and even catnip. Leaves are used in the traditional foods of many cultures (**Figure 10**).

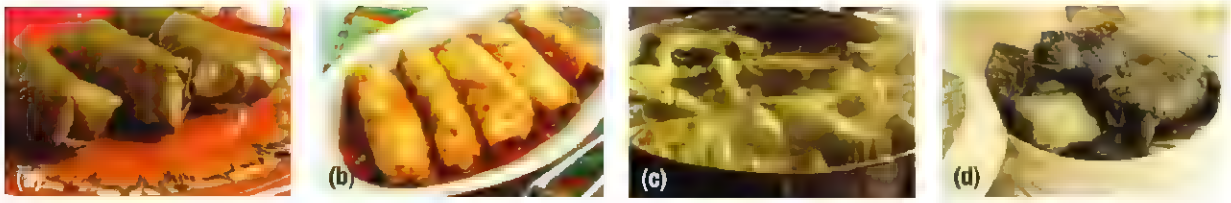


Figure 10 (a) A traditional Greek food called dolmades is made from grape leaves stuffed with rice or meat. (b) Cabbage rolls are cabbage leaves stuffed with meat or rice. (c) Tamales, a traditional South American food, are sometimes cooked in banana leaves. (d) Asian sticky rice is cooked in bamboo leaves.

CAREER LINK

Cosmetic Chemist

Cosmetic chemists use many substances produced by plants in their products. To learn more about becoming a cosmetic chemist,

GO TO NELSON SCIENCE

Dark green leafy vegetables, such as spinach, are especially nutritious. They contain important minerals, such as calcium, potassium, iron, and magnesium, as well as vitamins B, C, E, and K. They also provide nutrients that protect our cells from damage, such as beta-carotene, lutein, and zeaxanthin. Dark green leaves also contain small amounts of omega-3 fats, which are essential for brain and heart function.

Humans have found many uses for the waxy cuticle of leaves. For example, the wax produced by carnauba palm leaves is used to make car and furniture polishes. It is also used in surfboard waxes. It is sometimes an added ingredient in chocolate and is also used as a coating for candies. Candelilla wax, produced by a Mexican desert plant, *Euphorbia cerifera*, is a soft wax used to make lipstick.

Leaves are also used in religious ceremonies. The leaves of the sweet grass plant (also called buffalo grass) are widely used in North American Aboriginal peoples' religious ceremonies. For example, the Cree and Anishinaabe Algonquian peoples burn braided sweet grass at the start of all ceremonies, to purify the spirit. Christians use palm leaves in Easter ceremonies.

Leaves are even used as construction materials. In tropical countries, thatched roofs are made from the leaves of palm trees.

Leaves and Chemicals

Many species protect themselves by synthesizing toxic chemicals in their leaves. Many leaf chemicals are poisonous to humans. For example, the leaves of many house plants and even some vegetables contain toxins that can be harmful to humans if eaten. Consuming hydrangea leaves can cause vomiting, diarrhea, and even coma. Interestingly, we can eat the leaf stalks of the rhubarb plant, but eating the leaf blades could cause vomiting, nausea, and, in some cases, kidney damage.

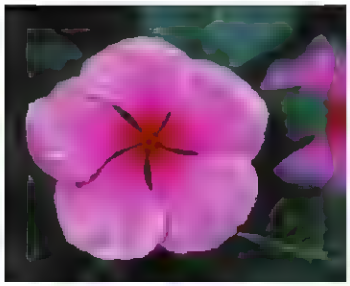


Figure 11 The rosy periwinkle is a source of two cancer-fighting drugs.

However, humans have discovered how to use some plant toxins in beneficial ways. Digitalis is a drug used to treat heart disease. It can be deadly, but it is beneficial when used in very small amounts. Digitalis was first isolated from the leaves of the foxglove, an ornamental garden plant.

Some plant poisons can be beneficial in cancer treatment. This is because the toxins produced by some plant leaves can be used to kill the rapidly dividing cancer cells. For example, vincristine and vinblastine are poisonous chemicals produced by the leaves of the rosy periwinkle (**Figure 11**). Vincristine is used to treat childhood leukemia, and vinblastine is used to treat Hodgkin's disease.

PSYCHOTROPIC DRUGS

Some plants produce deterrent chemicals that affect the nervous systems of some species. Research suggests that these chemicals could protect the plant by partially debilitating the herbivores that ate them. These chemicals are **psychotropic**, meaning they alter perception, emotion, or behaviour. For example, one species of the cannabis plant (marijuana) produces the psychotropic compound tetrahydrocannabinol (THC). THC has medical uses. It can increase appetite and reduce nausea, and may reduce muscle spasms. These properties make it useful for lessening symptoms of various diseases. It also reduces internal pressure in the eye, which makes it useful in treating glaucoma. However, since it is psychotropic, THC causes distorted perceptions, impaired coordination, difficulty in thinking and problem solving, and problems with learning and memory, which can have serious consequences.

psychotropic mind-altering

WEB LINK

Canadian doctors can prescribe marijuana to treat a number of conditions. To learn more about the use of medical marijuana in Canada,

GO TO NELSON SCIENCE

The leaves of the coca plant also produce a psychotropic substance. The coca plant is native to the slopes of the Andes in South America, and the local indigenous peoples chew the leaves because it suppresses hunger, pain, and fatigue and helps lessen the symptoms of altitude sickness. Coca leaves, when chewed or made into a tea, are only mildly stimulating. In the nineteenth century, German chemists isolated the active substance in the coca leaf, cocaine. Cocaine was used medicinally as an anesthetic and a stimulant. It was also widely available to the public in the form of pills and cigarettes. Cocaine can produce euphoria, talkativeness, and alertness. It can also produce paranoia, irritability, and nervousness. By the turn of the twentieth century, it became evident that cocaine is highly addictive to humans, and it was banned in many countries. Cocaine addiction continues to be a huge social problem.

12.2 Summary

- The leaf is the primary site of photosynthesis and gas exchange.
- Leaves have adaptations for protecting the plant from herbivores.
- Some leaves have specializations for storage or protection against the cold.
- Monocots and eudicots have different venation patterns in their leaves.
- Humans use plant leaves for food, medicine, and waxes, and in religious ceremonies.

12.2 Questions

1. What functions do leaves serve to the plant? K/U
2. How do monocot and eudicot leaves differ? K/U
3. Describe the function of the following: epidermis, cuticle, mesophyll, guard cells. K/U
4. Explain how the organization of cells in the palisade mesophyll and spongy mesophyll in a typical vascular plant help fulfill the leaf's roles. K/U
5. (a) Describe why sub-zero temperatures can damage some types of leaves. K/U
   (b) Describe the adaptation that angiosperm trees have to cope with below-freezing temperatures, and explain how this adaptation helps the plants. K/U
6. Health experts constantly remind us to eat leafy vegetables. Explain why. T/I
7. You are given the leaves of one plant from a desert environment and one from a rainforest. Predict the differences you would see in each of the leaves that would make it more adapted to its environment. T/I A
8. Identify at least one food you enjoy that uses leaves as an ingredient in its preparation. Identify the leaf or leaves that are used in the recipe. A
9. There are many sources of food, fibres, medicines, and waxes other than leaves. If leaves did not exist, would human life suffer? Why or why not? C A
10. Most plant leaves contain toxic or foul-tasting compounds. How do they benefit the plant? In what ways have these compounds been beneficial and harmful to humans? K/U A

12.3

Stems

Figure 1 The stems of trees are an important economic resource.

Figure 2 The green part of a cactus is its stem, modified to store water and nutrients and to perform photosynthesis.

If you pass a building site or walk through a lumber yard, you will likely encounter one of the most common uses of stems. The stems of tree species are the source of wood (**Figure 1**). Any wooden boards, planks, and sheets you see come from the stems of a number of tree species, such as pine and ash. Stems in the form of tree trunks are worth a great deal to our economy. According to Statistics Canada, in 2009 the gross value of forestry and logging was $3.5 billion. The harvested wood is often converted to wood products, further contributing to our economy. For example, Industry Canada reported that Canadian pulp and paper was worth $9.8 billion in 2008.

The uses for stems go far beyond the lumber yard. The origins of these two common products might surprise you. Cinnamon, a popular spice, is powdered bark from a laurel tree. Chewing gum originally came to Europe from South America, where explorers saw Mayans chewing the sap of the chicle tree.

Functions of Stems

Stems are certainly valuable to our economy, but what value are they to plants? Stems have several important roles. They connect the vascular tissue in the leaves to the vascular tissue in the root. This allows water and dissolved substances to be transported throughout the plant body. Stems also raise and support the leaves and reproductive organs. Raising leaves helps to maximize their exposure to sunlight, so they are able to photosynthesize more efficiently. Raising flowers or cones places them in an ideal position for pollination and the production of seeds and fruit. In some species, stems may also be modified to store water or carbohydrates. For example, cactus stems are highly modified to allow storage (**Figure 2**). Cacti, aspen trees, and many other plants have green stems that perform photosynthesis. The stems of many species have adaptations to help protect the plant from injury and herbivores. For example, thorns, such as those on the hawthorn tree, are modified branches that form sharp spikes that deter large herbivores.

Stem Structure

herbaceous describes plants with stems that do not have wood

woody describes plants with stems that contain wood

The plants in **Figure 3** show the diversity of stem types found among plant species. This diversity occurs in part because some species have herbaceous stems and some have woody stems. **Herbaceous** plants have stems that do not contain wood. Their stems are relatively pliable, carry out photosynthesis, and have a thin epidermis. As the name suggests, **woody** plants have stems that contain wood. Woody stems are relatively hard, have bark, and do not usually carry out photosynthesis. All gymnosperms have woody stems. Most woody angiosperms are eudicots. Monocots do not produce wood, but some have tissues that have a similar function, such as the stems of some palms and bamboos.

Figure 3 (a) The herbaceous stems of the asparagus plant are a source of food for humans and other organisms. (b) The baobab tree is native to dry regions of Africa, Malaysia, and Australia. The wide, woody stem can store large amounts of water.

Anatomy of Herbaceous Stems

Figure 4 shows the general anatomical features of herbaceous stems of monocots and eudicots. The vascular tissue of herbaceous stems is arranged in distinct vascular bundles in ground tissue. A **vascular bundle** is a long, continuous strand of vascular tissue that consists of xylem and phloem. Vascular bundles run continuously from the root to the leaves. In each vascular bundle, the xylem is always closer to the centre of the stem, and the phloem is always closer to the outside of the stem. Vascular bundles are arranged differently in monocot and eudicot stems. In monocots, the vascular bundles are found throughout the ground tissue of the stem. In eudicots, the vascular bundles form a ring.

vascular bundle the arrangement of vascular tissue that consists of xylem and phloem

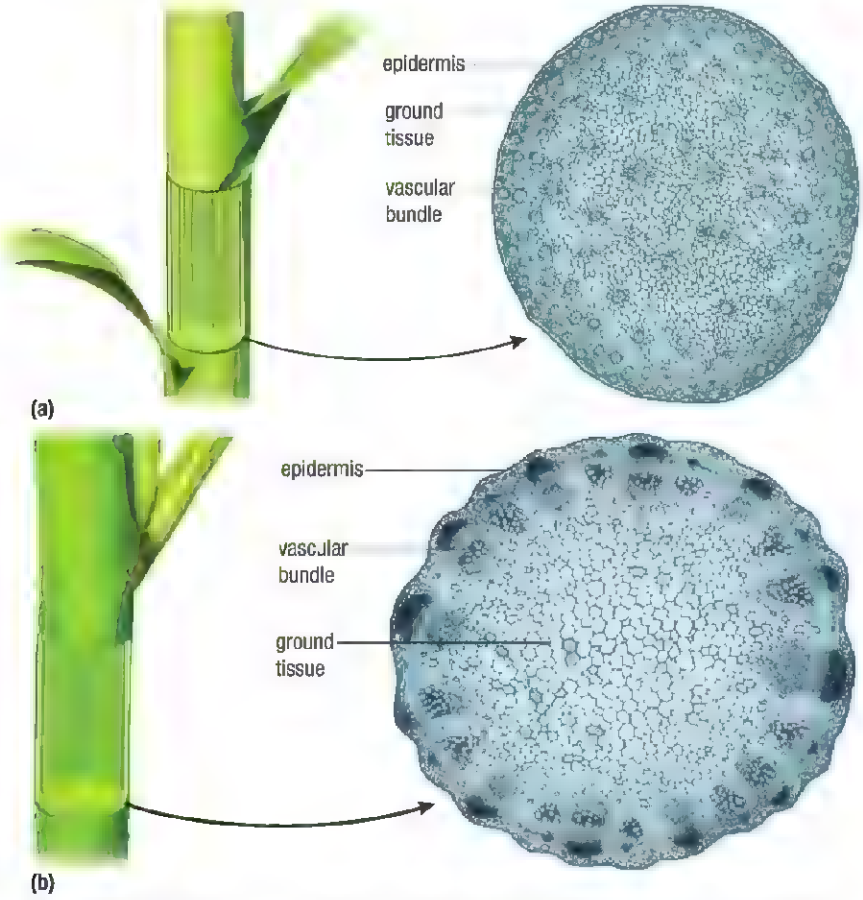


Figure 4 Stem structures of monocots and eudicots: (a) longitudinal view and a cross-section of a monocot stem (corn); (b) longitudinal view and a cross-section of a eudicot stem (alfalfa)

Investigation 12.3.1

Comparing Monocot and Eudicot Stem Cross-Sections (page 576)
Now that you have read about the structure and function of stems, you can complete Investigation 12.3.1.

In this observational study you will prepare and observe slides of cross-sections of monocot and eudicot stems.

Anatomy of Woody Stems

Woody stems have a more complex structure than herbaceous stems. Woody stems are able to grow thicker over the years due to the presence of vascular cambium. **Vascular cambium** is a layer of meristematic cells in the vascular tissue that divide to form new xylem and phloem cells. Each year, the vascular cambium produces a layer of xylem and phloem tissue. The xylem tissue is on the inside of the vascular cambium and the phloem tissue is on the outside.

vascular cambium the meristematic cell layer in vascular tissue

What we call "wood" is actually many layers of xylem tissue cells. Sapwood is the younger xylem through which water and minerals are transported to the leaves. Eventually, the cells in older xylem layers fill up with resins and oils and they no longer conduct water. These older xylem layers form the heartwood. Heartwood is very rigid and helps support the tree.

The anatomy of a typical woody stem is shown in **Figure 5**.

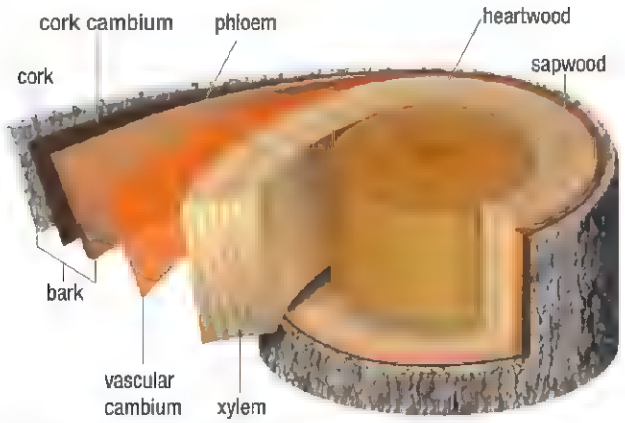


Figure 5 Cross-section of a typical woody stem. The light and dark rings in the heartwood and softwood are xylem, organized into growth rings.

bark the protective outermost layer of the stems and roots of woody plants; consists of phloem, cork cambium, and cork

cork cambium the meristematic layer in a woody plant that produces cork

Bark consists of all the tissues found outside the vascular cambium. It includes phloem, cork cambium, and cork. The phloem transports sugars made in the leaves throughout the plant. The **cork cambium** is a layer of meristematic tissue that produces cork, the tough, outer layer of the tree that prevents water loss from the stem. As the stem increases in size, the cork often cracks and may flake off the tree. Bark protects plants from some herbivores and, in the case of certain tree species, including Ontario's red and white pine, can even offer protection from low-temperature fires.

GROWTH RINGS

In temperate regions, growth only happens in the spring and summer. In spring, the vascular cambium grows rapidly, producing large xylem cells that have relatively thin walls (**Figure 6**). This forms a layer of lighter-coloured wood, known as spring wood. In summer, fewer xylem cells are produced and they have thicker cell walls that form a layer of darker-coloured wood, known as summer wood. Together, these layers form a growth ring. Each ring has light wood on one side and dark wood on the other.

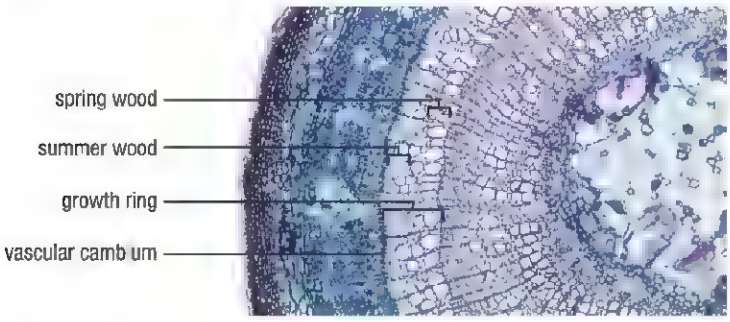


Figure 6 A two-year-old woody stem. Within the growth ring, the xylem cells are larger in spring wood than in summer wood.

Cell Types in Vascular Tissues

The structure of cells in both the xylem and phloem tissues helps the vascular tissue carry out its functions of transport and support. Xylem cells are thick walled and dead at maturity. The cell walls of xylem are rich in lignin, a carbohydrate that makes the cells very strong. Phloem cells are living at maturity and contain cytoplasm. Both phloem and xylem cells may be stacked to form long, continuous tubes.

There are two types of xylem cells: tracheids and vessel elements. A **tracheid** is a long, cylindrical cell with tapered ends (**Figure 7(a)**). All the cell walls of a tracheid have pits (small holes) that allow water and solutes to pass up or across to neighbouring xylem cells. A **vessel element** is shorter and wider than a tracheid and has less-tapered ends (**Figure 7(b)**). Only the side cell walls of vessel elements have pits. The other walls are **perforation plates**, which are end walls with one or more openings to allow water and solutes to pass through.

Phloem cells are living at maturity and contain cytoplasm. Three types of phloem cells are found in vascular plants: sieve cells, sieve tube elements, and companion cells. **Sieve cells** have narrow pores in all their cell walls and contain all the organelles found in most cells, including a nucleus. **Sieve tube elements** have cytoplasm but lack many cell organelles, including a nucleus. The end walls of these cells are called **sieve plates**, which are cell walls with perforations to allow sugar solutions to pass to the neighbouring phloem cells. The third type of phloem cell is a **companion cell**, which is always associated with a sieve tube element. It has a nucleus and all the other organelles that the sieve tube element lacks. The sieve tube elements and their associated companion cells form long conducting tubes (**Figure 7(c)**).

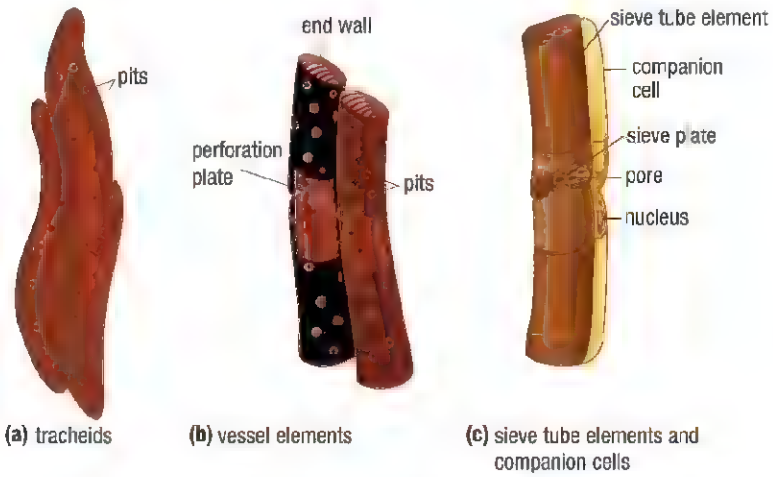


Figure 7 (a) Tracheids have pits in the cell walls that allow transport between neighbouring xylem cells. (b) Vessel elements have a perforation plate at each end of the cell in addition to pits in the side walls. (c) The phloem of angiosperms includes sieve tube elements and their associated companion cells. The companion cells direct the metabolic functions of the sieve tube elements. Each end wall of a sieve tube element contains a sieve plate, which has pores to allow transport between other sieve tube elements.

Not all vascular plants contain all the different types of xylem and phloem cells. **Table 1** shows the cell types most commonly found in the vascular tissue of gymnosperms and angiosperms.

Table 1 Xylem and Phloem Cell Types in Gymnosperms and Angiosperms

Plant group	Xylem tissue cell types	Phloem tissue cell types
gymnosperms	tracheids	sieve cells
angiosperms	tracheids vessel elements	sieve tube elements companion cells

tracheid an elongated, tapered xylem cell with thick cell walls containing small pits; tracheids overlap one another at the ends to form continuous tubes from root to shoot

vessel element a shorter, blunt-ended xylem cell with thick cell walls containing small pits; vessel elements are stacked end to end to form vessel tubes that run from root to shoot

perforation plate the perforated end wall of a vessel element

sieve cell a phloem cell with pores in its cell walls; contains all necessary cell organelles

sieve tube element a phloem cell with pores in its side cell walls and a sieve plate at the end walls; sieve tube elements lack organelles and depend on associated companion cells

sieve plate the perforated end wall of a sieve tube element

companion cell a small, nucleated phloem cell that is always associated with a sieve tube element

Stem Specializations

All stems connect the vascular tissue of the plant shoot and root, but not all types of stems hold plants upright. Some stems grow underground and are modified to store food and water. Underground stems can also give rise to a new plant.

Figure 8 shows examples of the three types of underground stems: tubers, corms, and rhizomes.

Figure 8 Underground stems: (a) potato tuber, (b) gladiolus corm and (c) iris rhizome

Stolons are modified stems that grow along the soil instead of upright. Spider plants produce new plants on the ends of stolons (**Figure 9(a)**). Vines are plants with modified stems that take advantage of other objects, including other plants, to raise and support their leaves. Vine stems may be woody, such as grape stems (**Figure 9(b)**), or herbaceous, such as sweet pea stems (**Figure 9(c)**). The tendrils that hold up sweet pea vines are modified leaves.

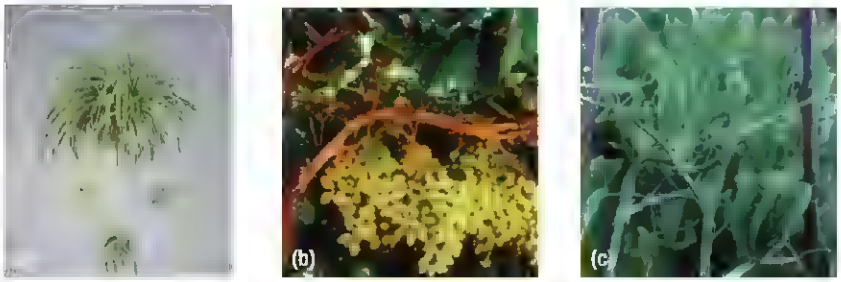


Figure 9 Above-ground modified stems are found on (a) spider plants, (b) grape vines, and (c) sweet peas.

Human Uses of Stems

The most obvious use of stems is in the many wood-based products we use, from furniture, to kitchen cabinetry, to the paper in books. However, humans use vascular plant stems, and the chemicals they contain, for a variety of other purposes (**Table 2**).

Table 2 Some Uses of Plant Stems

Use	Examples	Use	Examples
fuel	• ethanol • wood	dyes	• indigo, used to dye jeans • hematoxylin, a stain used to prepare microscope slides
food	• sugar cane • potatoes • yams • maple syrup • asparagus	other chemicals	• tannin, an ingredient in wood stains • turpentine, a solvent • latex rubber, used for many products, including gloves, tubing, and erasers
textiles	• flax (used to manufacture linen) • hemp (used to produce textiles) • bamboo (used to make clothing; often blended with other natural fibres such as cotton)	medicine	• salicylic acid, a pain reliever made from willow bark • taxol, an anti-cancer drug made from the bark and needles of yew trees

CAREER LINK

Engineering Technologist
The pulp and paper industry employs engineering technologists to help apply the plans of professional engineers to the production process. To learn more about this career,

GO TO NELSON SCIENCE

UNIT TASK BOOKMARK

You can apply your knowledge of the many ways we use plant stems to the Unit Task described on page 630.

Research This

Willow Bark and Modern Medicine

Skills: Researching, Analyzing, Communicating, Defin ng the Issue, Defending a Decision

SKILLS HANDBOOK A5.1

A number of Canada's Aboriginal peoples found that willow bark could be used medicinally to ease pain and fever.

1. Conduct research to find out how this traditional use of a plant stem eventually led to the production of one of the most widely known and life-saving medicines, acetylsalicylic acid (ASA).

A. How did Aboriginal peoples prepare and use willow bark? K/U

B. Willow grows in many places on Earth. Identify any other culture that used willow medicinally. K/U T/I

C. What is the active ingredient in willow bark? Why did the Bayer company chemically modify this substance? K/U T/I

D. How is ASA of benefit to people suffering from cardiovascular disease? T/I

E. The active ingred.ent in willow bark was first isolated in 1828. In 1899, the Bayer company completed clinical trials of ASA and made it available to physicians. Why was it important to conduct this research on willow bark? T/I A

GO TO NELSON SCIENCE

12.3 Summary

- Stems connect the vascular tissue from shoot to root and raise and support leaves and reproductive structures; they may perform photosynthesis, store water and/or carbohydrates, and have protective features.
- The structure of xylem and phloem cells helps the vascular tissue perform its transport role.
- Gymnosperms have woody stems; angiosperm stems may be woody or herbaceous.
- The vascular bundles are arranged randomly in herbaceous monocot stems and in a circle in herbaceous eudicot stems.
- Woody stems produce new xylem and phloem cells each year.
- Humans use stems for many purposes, such as for wood products, food, textiles, dyes, medicines, chemicals, and fuel.

12.3 Questions

1. What functions do plant stems fulfill for the plant? K/U
2. (a) What is cork cambium and what does it do? K/U
   (b) Do all plants have cork cambium? Explain. K/U A
3. In a table, compare and contrast the vascular tissue of gymnosperms and angiosperms. Consider the types of stems, the xylem and phloem cells, and the arrangement of the t ssue within the stem. K/U C
4. (a) Do mature cells of xylem tissue have nuclei? Explain. K/U
   (b) Do mature cells of phloem tissue in angiosperms have nuclei? Explain. K/U
5. Using the information in this section, give your opinion on the economic value of stems to Canadian society. K/U A
6. The rubber tree is grown for its sap and wood (**Figure 10**). The collected sap is processed to produce natural rubber. The companies that own these plantations sometimes advertise their products as environmentally sustainable. Use the Internet and other sources to check this claim. Report on your findings. C A

Figure 10 Natural rubber is a renewable resource.

GO TO NELSON SCIENCE

12.4 Roots

Roots are usually hidden from view and are rarely thought attractive. However, roots can have surprising beauty. **Figure 1** shows the Ta Prohm temple in Cambodia. The temple is almost completely overgrown by the roots of banyan and kapok trees. It is a popular tourist attraction and has been used as a location in a number of movies.

Figure 1 The beauty of the Ta Prohm temple is in part due to the large roots that cover it.

Function of Roots

A main role of plant roots is to anchor the plant and keep it upright. Another main role of roots is to absorb water and nutrients other than carbohydrates (which are produced by photosynthesis). Some roots store water and carbohydrates for the plant.

Types of Root Systems

taproot system a root system composed of a large, thick root; can have smaller lateral roots

lateral root a smaller root that branches from a larger root

root hair a microscopic extension of the epidermal cells of the root

fibrous root system a root system made up of many small, branching roots

If you have ever done work in a garden, you have likely noticed that there are two basic types of root systems. A **taproot system** has a large, thick, main root called a taproot, which grows straight downward (**Figure 2(a)**). The taproot may also have **lateral roots** branching from it. Both taproots and lateral roots are covered with root hairs. A **root hair** is a microscopic hair-like outgrowth from an epidermal cell. Taproots are able to push deep into the soil. Gymnosperms and angiosperm eudicots have taproot systems.

In contrast, a **fibrous root system** has many small roots (**Figure 2(b)**). Each of these roots may have lateral roots. Like taproots, fibrous roots have root hairs. Fibrous roots tend to be shallower than taproots. Fibrous roots occur in angiosperm monocots.

(a) (b)

Figure 2 Both types of roots, (a) taproots and (b) fibrous roots, can have lateral roots.

General Structure of Roots

All roots have the same general structure (**Figure 3**). The tip of the root contains the root cap and a meristem. The **root cap** is a thick layer of cells that produce a slippery substance that helps the root to penetrate the soil, minimizing damage to the root cells. The meristem produces new cells to increase the length of the root.

The root hairs are found above the root tip, projecting outward from the epidermis of the plant root (**Figure 4(a)**). Root hairs dramatically increase the surface area of the epidermis. As a result, the root can absorb water and dissolved nutrients much more efficiently. The **root cortex** is a region of parenchyma cells beneath the epidermis. The cells of the root cortex store carbohydrates and also help transport water from the epidermis to the xylem. The root cortex ends at the **endodermis**. The walls of the cells in the endodermis are wrapped with a wax-like substance, forming a continuous barrier called the **Casparian strip** (**Figure 4(b)**). (You will learn about the function of the Casparian strip in the next section.)

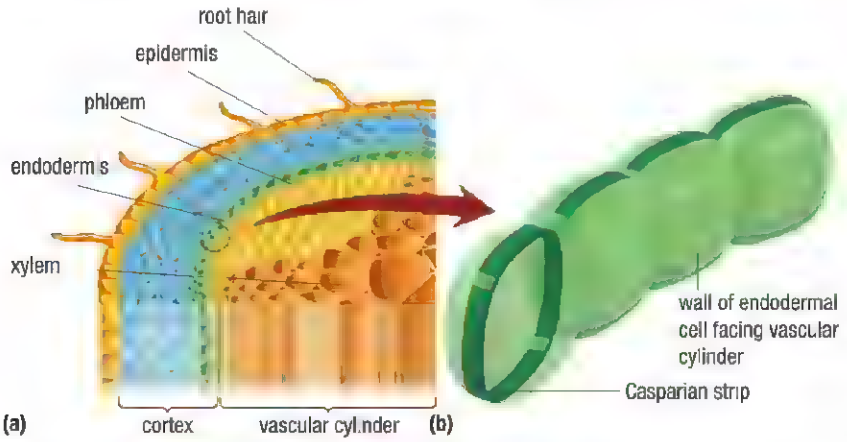


Figure 4 (a) The general features of a root (b) Each endodermal cell has a Casparian strip in its cell wall

The vascular tissue of roots is contained in the **vascular cylinder**. The arrangement of xylem and phloem within the vascular cylinder varies among the groups of angiosperms (**Figure 5**). In gymnosperms and eudicots, the centre of the root contains xylem cells forming an "X" or star-shape in the centre of the vascular cylinder. The phloem cells are also in the centre of the root, around the xylem. In monocots, however, the centre of the root contains parenchyma cells. These cells are surrounded by a ring of xylem cells and a ring of phloem cells.

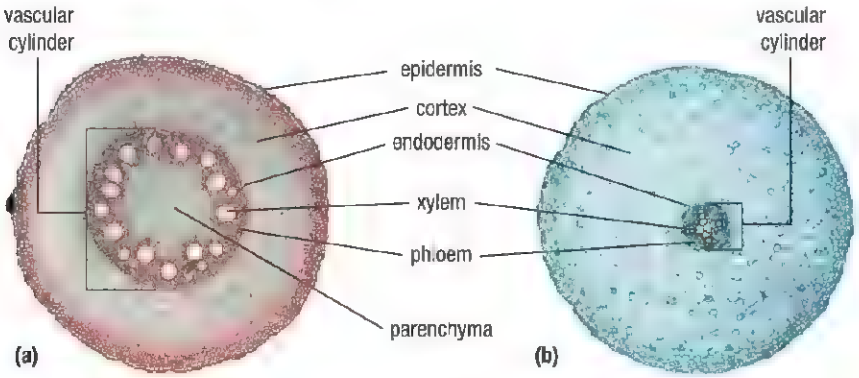


Figure 5 Cross-sections of (a) a monocot root and (b) a eudicot root. In monocots, the centre of the vascular cylinder has parenchymal cells. In eudicots xylem cells are at the centre of the root.

As in stems, the roots of gymnosperms and some eudicot species form wood as the plant ages. The anatomy of a woody root is very much like that of a woody stem. Woody roots are made up primarily of xylem, which forms growth rings.

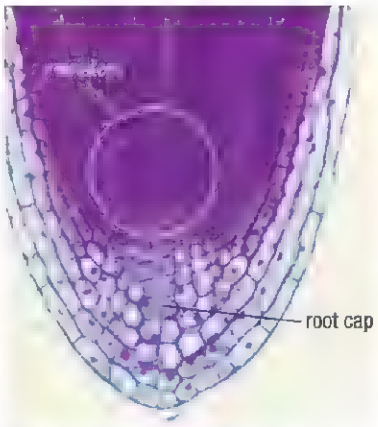


Figure 3 The root tip contains the root cap and a meristem.

root cap the mass of cells that form a protective covering for the meristem at the root tip

root cortex a region of parenchyma cells under the epiderm s of a root

endodermis the innermost layer of cells in the cortex of a root

Casparian strip the wax-like strip that runs through the cell wall of an endodermal cell

vascular cylinder the central portion of a root that contains the xylem and the phloem

Investigation 12.4.1

Comparing Monocot and Eudicot Root Cross-Sections (page 577)
Now that you have read about the structure and function of roots, you can complete Investigation 12.4.1.

In this observational study you will compare and contrast prepared slides of root cross-sections from a number of plant species and create labelled biological drawings.

Root Specializations

UNIT TASK BOOKMARK

Will root specializations be a factor you will consider as you evaluate the importance of a species for the Unit Task on page 630?

Root specializations may help roots to more efficiently absorb water and nutrients, anchor the plant, or store carbohydrates. Other specializations help protect the plant root from being eaten.

A primary role of a root is to absorb water and nutrients for the plant. Almost all plants have some kind of relationship with other organisms to help them in this task. In fact, the roots of over 80 % of plants have a mutualistic relationship with mycorrhizal fungi (**Figure 6**). These fungi can get into smaller spaces in the soil than root hairs can, and are able to release digestive enzymes that break down organic matter. The fungi exchange water and nutrients with the plant in return for carbohydrates. Another important mutualistic relationship occurs between roots of some plant species and nitrogen-fixing bacteria. The bacteria take nitrogen from the air and convert it to a form that the plant can use. In return, the bacteria receive carbohydrates. The bacteria live within nodules in plant roots.

Figure 6 Plants grown in soil that lacks mycorrhizae tend to be smaller than plants that have mycorrhizae.

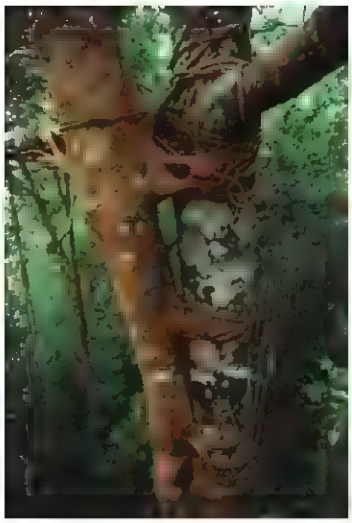


Figure 7 The strangler fig roots (left) encircle the host tree (right) and eventually kill it by cutting off the flow of materials between the roots and leaves.

tuberous root a lateral root specialized to store carbohydrates

Some species, such as the strangler fig, have unusual relationships with other organisms. This plant is found in tropical rain forests. Monkeys, birds, and other animals deposit seeds of the strangler fig in the branches of other trees. These trees become the host in the relationship. As the seed begins to grow, its roots hold on to and obtain water and nutrients from the crevices in the host tree trunk. The roots also grow downward, wrapping around the trunk of the host tree until they reach the soil (**Figure 7**). The fig's shoot system at first grows slowly, shaded by the leaves of the host tree. Eventually, the fig's roots prevent the host's trunk from growing outward. This kills or "strangles" the host tree. As the host tree dies, it loses all its leaves. The fig shoot system is now in the open sun and grows rapidly, and its root system completely engulfs the trunk of the host. The host tree trunk rots away, leaving behind a large hollow space within the strangler fig.

Most of the roots eaten by humans and other organisms are specialized for carbohydrate storage. For example, carrots and beets are taproots that have a thicker cortex for greater carbohydrate storage (**Figure 8(a)**). In other species, the lateral roots are specialized for storage. Lateral roots modified for storage are called **tuberous roots**. Yams, cassava, and sweet potatoes are tuberous roots that are important for our food supply (**Figure 8(b)**).

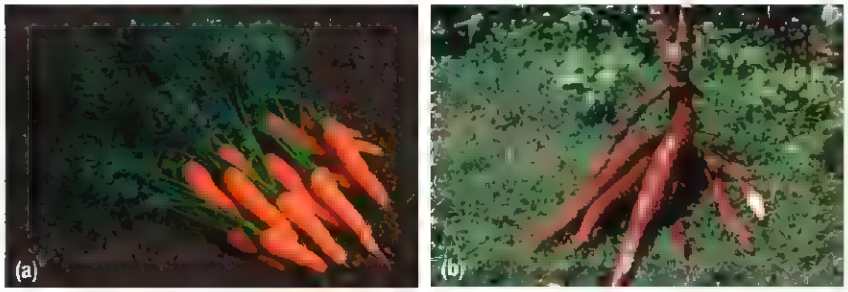


Figure 8 (a) Taproots, such as carrots, and (b) tuberous roots, such as cassava, store carbohydrates in a thick layer of parenchyma cells.

Roots that store carbohydrates are at higher risk of being eaten by other organisms. Some roots therefore produce chemicals to reduce this risk. For example, the roots of the plants called bitter root and bear root taste so bad that few animals will eat them. Cassava roots protect themselves by producing a deadly toxin. To make cassava root safe to eat, humans soak and cook it, which removes the toxin. Some insects, such as the mealy bug, are resistant to the cassava root toxin.

The roots of some plants produce chemicals that harm other plants. Two examples are the black walnut and the common reed. The black walnut root secretes a toxin that inhibits the growth of other plants. The common reed releases a corrosive acid that breaks down the roots of neighbouring plants. Preventing other plants from growing nearby reduces competition for resources.

Figure 9 shows an example of a root adaptation that gives additional support to the plant. In this example the prop roots are growing from the stem of a young corn plant. A prop root is a type of adventitious root. An **adventitious root** is any root that does not grow from the root apical meristem that emerges from the seed after it begins to grow.

Figure 9 The adventitious roots provide the corn plant with additional support. These are also known as prop roots.

adventitious root a root that develops from somewhere other than the root apical meristem that emerges from the seed

Human Uses of Roots

As with leaves and stems, humans have found many ways to benefit from the diversity among roots of vascular plants. We use roots as food, for ourselves and our livestock, and as a source of useful chemicals.

Many of the vegetables we eat are roots, including parsnips, turnips, beets, taro, and sweet potatoes. Licorice root has a distinctive flavour that is sometimes used in candy. Roots may also be used to make beverages. For example, root beer was originally prepared from the root of the sassafras plant. Cassava, turnips, yams, rutabaga, and other roots are used widely to feed livestock.

There are many uses for the wide variety of chemicals produced by roots. Some roots can be used to dye textiles. For example, red dyes can be prepared from roots of beet or madder, and dandelion root can be used to dye textiles brown. Some pesticides, such as rotenone, come from roots. Rotenone is produced by the roots of plants in the pea family to protect them from being eaten. Rotenone may be used to control insects in gardens or on pets.

As with some leaves and stems, the roots of some plants produce chemicals that have medicinal uses. Ipecac is a substance that may be given to someone who has swallowed something poisonous. Ipecac will rapidly induce vomiting and prevent any further absorption of the poison. (In all cases of suspected poisoning, do not attempt any treatment. Go directly to a hospital.) Ipecac is produced by the root of the ipecacuanha plant, native to Brazil (**Figure 10(a)**). Kava kava root produces a substance that has been shown in scientific studies to reduce anxiety. Scientists are working to identify the active ingredient (**Figure 10(b)**).The root of valerian, a common garden plant (**Figure 10(c)**), produces a mild sedative that can be used to relieve insomnia.

CAREER LINK

Pharmacist

Pharmacists have knowledge of potential interactions between over-the-counter herbal remedies and prescription drugs. To find out more about a career as a pharmacist,

GO TO NELSON SCIENCE

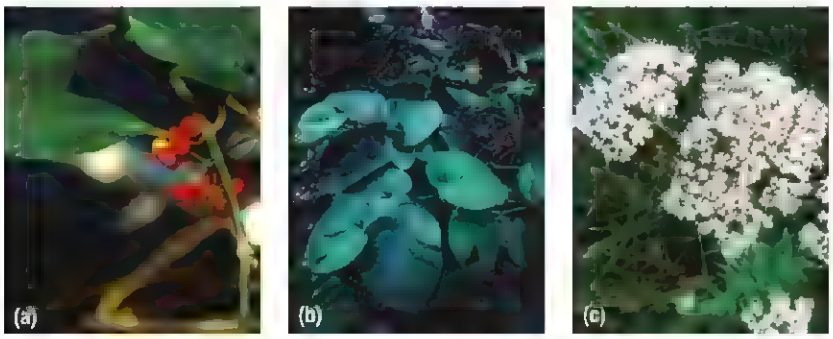


Figure 10 Chemicals in the roots of (a) ipecacuanha, (b) kava kava, and (c) valerian have medicinal uses that have been verified by scientific studies.

Mini Investigation

Identifying Starch in Roots

Skills: Questioning, Performing, Observing, Analyzing, Communicating SKILLS HANDBOOK A2.1

Most of the roots eaten by humans are taproots. Taproots have many parenchyma cells, which store sugars and starch. Young roots tend to be sweeter, since they have not yet converted as much sugar to starch. Starch does not support bacterial growth as well as sugar, so roots can remain edible for a long time when stored properly. The presence of starch can be detected using an iodine solution known as Lugol's solution.

Equipment and Materials: knife; Petri dishes; Lugol's solution; starch; samples of roots

Caution: Lugol's solution is toxic if swallowed and may stain skin and clothing.

1. Bring small samples of roots, including some that you think might be starchy root vegetables, to class.
2. Copy **Table 1** into your notebook. Ensure that there is enough space for all your samples.

Table 1 Test for Starch Using Lugol's Solution

Sample	Appearance before test	Appearance after test
starch		

3. Place a small sample of starch in a Petri dish.
4. Place a small piece of each root sample in another Petri dish.
5. Observe the appearance of each substance, and record your observations in your table.
6. Carefully add one drop of Lugol's solution to each sample.
7. Observe the appearance of each substance and record your observations in your table.

A. Why was the known starch sample tested with Lugol's solution? A7

B. Which of your samples contained starch? How did you determine this? A7

C. Give two reasons why you would not taste an unknown food sample to determine whether it contains starch. A

Erosion Control

Figure 11 Special mixtures containing grass seeds may be sprayed on areas vulnerable to erosion.

Roots are extremely useful in helping to control erosion. Any area where soil is uncovered or sparsely covered is susceptible to wind and water erosion. Fibrous roots can be particularly useful in controlling erosion, since they form a mat that holds the upper soil layers in place during heavy rain, snow, or wind. You may have seen a strange green substance on piles of excavated soil on construction sites. This is actually an erosion control measure. It is mixture of grass seed, mulch, and synthetic additives that help the seeds grow quickly (**Figure 11**).

Trees may also be planted to control erosion. This is often done after an area of forest has been clear-cut, which involves harvesting all the trees in the area. Clear-cutting exposes the soil surface, making it vulnerable to erosion. However, even when tree seedlings are planted to replace the harvested trees, it takes many years for them to grow large enough to control erosion effectively.

Mangrove trees seem unusual to those of us who did not grow up around them. The roots of the mangrove arise from the above-ground portion of the stem (**Figure 12**). They are found at the shorelines of tropical seas, where they have an important role in controlling erosion. They also provide protected areas for the young of many marine organisms.

Figure 12 The characteristic roots of mangrove trees prevent erosion by waves.

12.4 Summary

- Roots anchor the plant, absorb water and minerals from the soil, and often store starch and sugars.
- All gymnosperms have taproots. Angiosperms may have either taproots or fibrous roots.
- All roots have a cortex and a vascular cylinder. Monocot roots have parenchyma cells in the centre of the vascular cylinder.
- Most plant species have symbiotic relationships with micorrhizal fungi that exchange water and nutrients with plant roots
- Some plants have mutualistic nitrogen-fixing bacteria living within specialized root nodules.
- The roots of woody gymnosperms and angiosperms have a similar structure.
- Humans use roots for many purposes.

12.4 Questions

1. What are the biological functions of plant roots? K/U
2. Draw a diagram of a fibrous root system. In what plant group are fibrous root systems found? K/U MC
3. Draw a labelled diagram of a cross-section of a monocot root. Include the following labels: cortex, vascular cylinder, parenchyma, xylem, and phloem K/U MC
4. Can you tell the difference between monocots and eudicots by looking at root cross-sections? Why or why not? K/U
5. A student wants to test the effects of mycorrhizal fungi on the growth of a particular plant species. She has two identical plants and a solution containing the fungi in which roots may be dipped. Write a brief experimental design for the investigation. State the manipulated and responding variables, and any variables that must be controlled. INQ
6. Epiphytes are plants that live on other plants, usually trees. Use the Internet and other sources to find out more about these plants. K/U A
   (a) Are epiphytes common?
   (b) In what ecosystems are they most common and why?
   (c) What are some of the advantages and disadvantages of being an epiphyte?
7. The roots of legumes, such as peas and beans, have special nodules that are home to large numbers of bacteria. What benefit do these bacteria provide to the plant? What do they receive in exchange? K/U A
8. Mistletoe is a widely known parasitic plant that grows high in trees (**Figure 13**). Mistletoe gets water and minerals from its host plant. Predict which tissues in the host plant are infiltrated by the mistletoe roots. T/I A

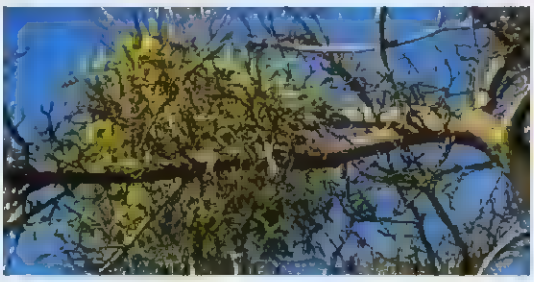


Figure 13 Mistletoe is a parasitic plant.

9. List two human activities that are likely to result in an increase in erosion. Explain your choices. A
10. Plants store most of their starch in their roots rather than in their leaves. This storage is often at its maximum over winter. K/U A C
    (a) How might these adaptations benefit the plant?
    (b) Based on this information, which plant part is likely to supply the greatest amount of food energy to other species—leaves or roots?
    (c) Suggest a way that humans have taken advantage of this over-wintering adaptation.
11. Grizzly bears are famously powerful animals. Use the Internet and other sources to find out the connection between their powerful limbs and plant roots.

GO TO NELSON SCIENCE

12.5 Transport in Vascular Plants

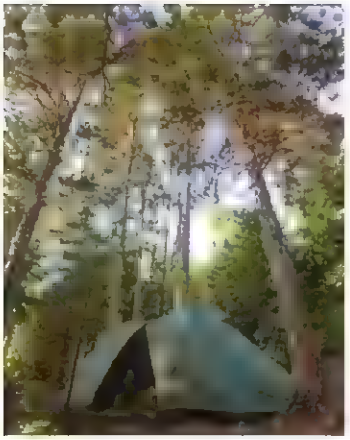


Figure 1 The tall trees in the old-growth forest of Temagami transport water and nutrients in the same way as all vascular plants on the forest floor

Lake Temagami is located in northern Ontario, northeast of Sudbury. Lake Temagami and the surrounding region are home to the largest old growth forests in Ontario (**Figure 1**). Old-growth forests have never been logged or otherwise altered by human activity and are very rare. Some trees in the Temagami forest are between 300 and 400 years old and have reached heights of 50 m and more. Unlike animals, plants lack a pump to move internal fluids. How do these trees get water and nutrients from their roots up to the leaves at their tops? How do they transport the products of photosynthesis to the vast number of cells they contain? You may be surprised to learn that vascular plants of all sizes use the same basic mechanisms to transport materials in their bodies.

Overview of Transport in the Plant

Figure 2 is an overview of the processes involved in the movement of substances in the plant. The water in the environment (either in the soil or in bodies of water, such as rivers and streams) is really a solution containing dissolved substances, including nutrients. For this discussion, this water will be called "soil water." Water moves between the xylem and phloem and is critical to the delivery of soil nutrients and sugars to all the cells of the plant. Sugars are transported solely in the phloem. Nutrients in the soil water are transported in the xylem.

CAREER LINK

Forester

Foresters may monitor the effect of human activities on the health and diversity of forests. To find out more about educational requirements and opportunities as a forester,

GO TO NELSON SCIENCE

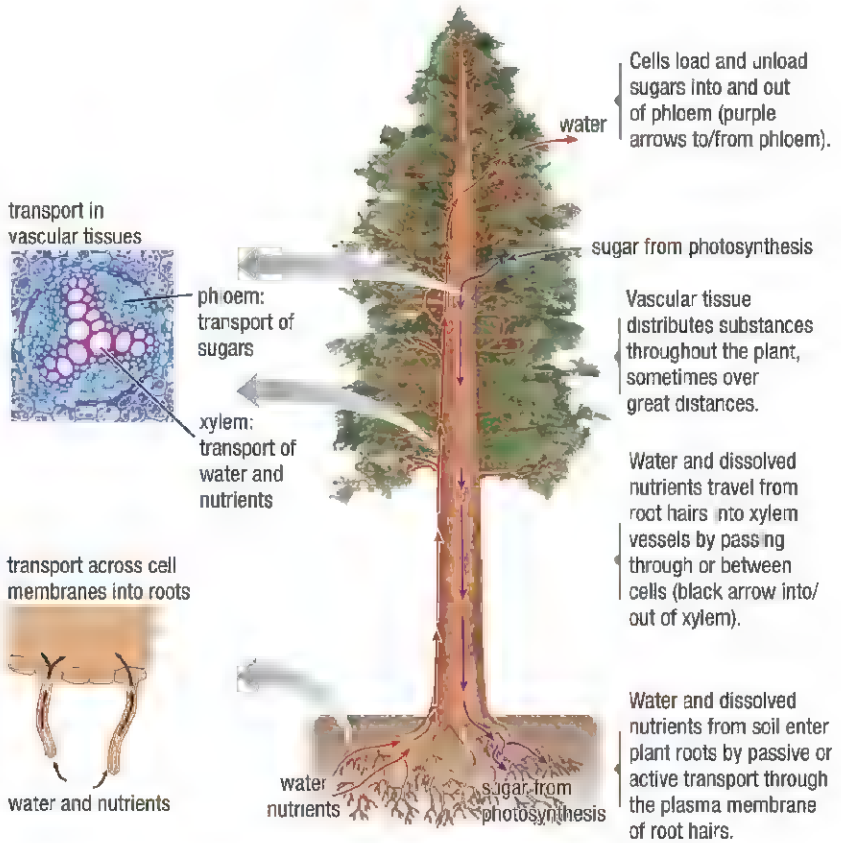


Figure 2 Overview of transport routes in plants

Transport of Water and Nutrients

Moving water and nutrients from the surface of a root hair all the way to the parenchyma cells in the leaves is a complex process. The same processes occur in plants in bodies of water. Water and nutrient transport involves three stages: (i) from the soil into the roots, (ii) from the roots to the stem, and (iii) from the stem to the leaves. Water also returns to the environment, mostly from the leaves.

Transport into the Root

Transport of water and nutrients into the root happens by two different processes: water enters the root cells by osmosis, but nutrients enter by active transport.

The cytoplasm of plant cells has a lower concentration of water molecules than the soil water, and the plant cell membrane allows water molecules to cross freely. Water molecules therefore enter cells in the plant root by osmosis. Recall that osmosis is the diffusion of water molecules across a selectively permeable membrane, from an area of higher concentration to an area of lower concentration. Water molecules can also enter the root and move through the spaces between the cells before being absorbed by osmosis (**Figure 3**). Once inside the cells, the water molecules move toward the vascular cylinder.

The concentration of nutrients in the cytoplasm of a plant cell is higher than the concentration of nutrients in the soil water. Therefore, needed nutrients will not enter the root cells by diffusion. Instead, the plant must use active transport to move nutrients from the soil water into the root cells. Once the needed substances are within the cytoplasm of the outer root cells they are moved through the cells of the cortex toward the endodermis. This movement is made easier by the fact that adjacent plant cells have interconnecting strands of cytoplasm. Once nutrients (or water) enter a root cell they will not have to cross another cell membrane until they reach the vascular cylinder.

Once water molecules and nutrients reach the endodermis, they encounter the Casparian strip. The wax-like substance that makes up the strip prevents all substances from passing through the spaces between the endodermal cells. Therefore all substances entering the vascular cylinder pass directly through the endodermal cells. The key role of the Casparian strip is to prevent substances from leaking back into the cortex. Once inside the vascular cylinder, nutrients are actively pumped across cell membranes into the xylem.

LEARNING TIP

Passive and Active Transport
Passive transport does not require energy and involves movement of substances across a membrane from an area of high concentration to an area of low concentration. Active transport, however, always requires energy. In active transport, substances are transported across a membrane from an area of low concentration to an area of high concentration.

LEARNING TIP

Envisioning the Casparian Strip
The term "Casparian strip" can be used to refer to the strip around each cell in the endodermis, or it can refer to the barrier around the vascular cylinder, which is made up of all Casparian strips of the endodermal cells.

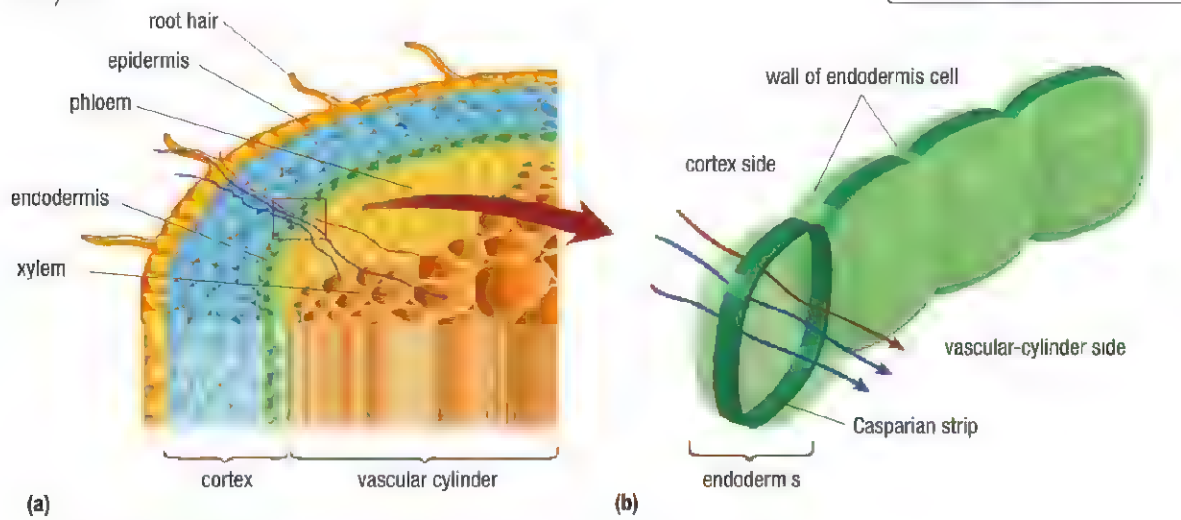


Figure 3 (a) Water moves through the cortex by two routes (blue arrows): it either flows between the cells or enters the cells by osmosis and then moves from cell to cell. Nutrients are taken in by active transport and move from cell to cell (red arrow). (b) At the endodermis, the Casparian strip prevents substances from passing between the endodermal cells and forces them to pass through the cell membrane instead. Nutrients enter the xylem by active transport.

Transport into the Stem

root pressure the osmotic force pushing xylem sap upward in root vascular tissue

capillary action the tendency of a liquid to rise or fall because of attractive forces between the liquid molecules

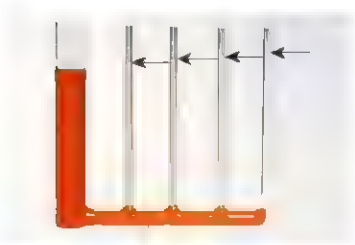


Figure 4 Capillary action increases as the diameter of the tube decreases.

Once water molecules and dissolved nutrients have crossed the Casparian strip, the liquid they form is called xylem sap. Substances in the xylem sap then move up the root toward the stem. How does the liquid sap move against gravity?

As more nutrients are actively pumped into the xylem, their concentration increases and water molecules follow by osmosis. In many plants this creates **root pressure** and helps push the xylem sap upward.

Capillary action, which is the tendency of a liquid in a narrow tube to rise or fall (**Figure 4**), also contributes to the rise of the xylem sap. In capillary action, a column of liquid is held together by weak attractive forces between molecules and rises because of attractive forces between the liquid and the sides of the tube. In the xylem tubes, attractive forces occur between different water molecules and between water molecules and molecules in the cell walls. The water molecules in the xylem sap stick to each other and are also drawn up the sides of the xylem tubes. As a result, the water column moves upward. Xylem sap also moves from one xylem tube to another, through the pits in the cell walls of xylem cells. Xylem sap can also move out of the xylem through the pits into the surrounding tissue. This ensures that all cells in the plant body receive water and nutrients, not just those at the top of the xylem column.

Mini Investigation

Transport in Xylem Tissue

Skills: Controlling Variables, Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK A2.1

In this investigation, you will observe how water is transported in the xylem of a carnation stem.

Equipment and Materials: two 50 mL beakers; masking tape; knife; hand lens; red and blue food colouring; one long-stemmed white carnation with leaves

Always cut away from yourself and others sitting near you in case the knife slips.

1. Place two 50 mL beakers beside each other in a well-lit area. Secure them in place with masking tape.
2. Add enough water so that the beakers are three-quarters full. Add 10 to 15 drops of blue food colouring to one beaker and 10 to 15 drops of red food colouring to the other.
3. Use the knife to cut a 1 cm section from the end of the carnation. This provides a fresh end.
4. Starting at the cut end, carefully cut the stem lengthwise for 10 cm. The lower half of the stem should now be cut into two equal halves, but each should still be attached to the intact part of the stem (**Figure 5 (a)**).
5. Place one half of the split stem in the beaker of red water and the other half in the beaker of blue water. Be careful not to bend, kink, or damage the stem (**Figure 5(b)**).

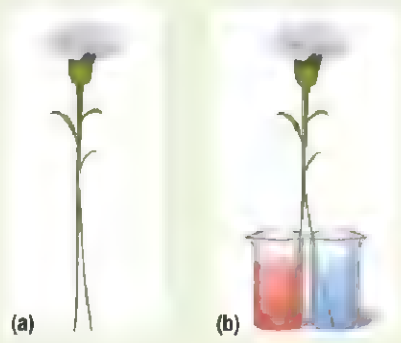


Figure 5 (a) Step 4 (b) Step 5

6. Let the carnation sit for 24 h. Then observe and record any changes in the stem or flower.
7. Remove the carnation from the beakers. Cut across the intact part of the stem, just above the lengthwise cut. Observe the cut end using a hand lens. Record your observations.

A. Describe the location(s) where you found food colouring in the carnation after 24 h. T/I

B. Was there any mixing of the two dyes? What does this tell you about the flow of liquid in the plant? T/I A

C. When you observed the cut through the stem diameter, did all cells contain dye? T/I

D. Relate your observations in B to your observations in C. T/I A

Transport to the Leaves

Capillary action and root pressure alone are not enough to get xylem sap all the way to the top of a tall tree. The main driving force of transport up the xylem actually comes from the leaves. Recall that the epidermis of leaves contains many stomata, the pores formed by guard cells. Plants release water vapour through their stomata during **transpiration**, which is evaporation of water from plant leaves. The water vapour evaporates through the stomata when they are open. Because of the attractive force between water molecules, when a water molecule moves up the xylem column, it pulls a neighbouring water molecule with it. The second molecule pulls the one behind it, and the "pull" continues down the length of the xylem. If a plant does not transpire, the water column will not move.

transpiration evaporation of water through the stomata of plant leaves

Figure 6 is an overview of how the different transport mechanisms in the root, stem, and leaf work together.

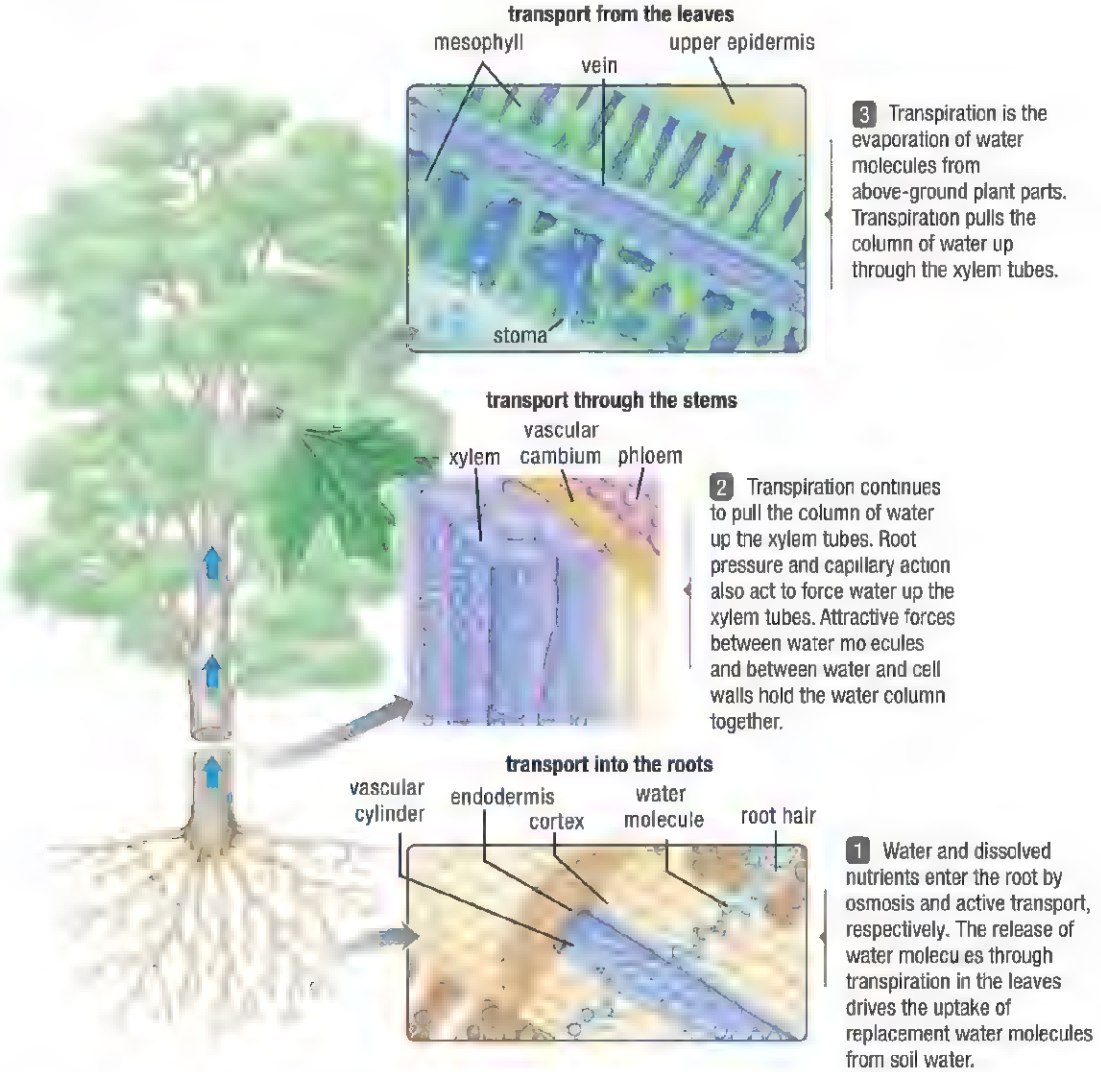


Figure 6 The transport of xylem sap from the roots to the leaves.

If a plant does not have sufficient water, it may wilt. A plant cell stores water and dissolved substances in its central vacuole. When the central vacuole is full, it exerts pressure against the cell wall; this pressure is called **turgor**. Turgor helps support the plant. When the plant is unable to take up water from the soil, water will move out of the vacuole and the plant will wilt.

turgor pressure caused by the fluid contents of the central vacuole, which pushes against the wall of a plant cell

Transport of Sugars

source a plant cell with a high concentration of sugars and other solutes, such as a leaf cell

sink a plant cell with a low concentration of sugars; sugars may be converted to starch for storage or used rapidly for energy or as building blocks of other carbohydrates

Plant cells use glucose and other sugars as a source of energy. In plants, sugars may be produced by photosynthesis or from breaking down carbohydrates in storage organs, such as tubers. A cell with a high concentration of sugars can be called a source. A photosynthesizing mesophyll cell is an example of a **source**. A **sink** is any cell that has a low concentration of sugar. A sink may convert sugars to starch for storage or use them rapidly. For example, cells that are rapidly growing are sinks, since they use up their sugar supplies quickly.

Direction of Sugar Transport

Unlike water and nutrients, which always move up the plant, sugars can move up or down the plant. The direction in which sugars are transported depends on the location of source cells relative to sink cells. In general, sugars are transported from a source to a sink, which are connected by columns of phloem cells. However, the location of sink and source cells in a plant may change. For example, the cells in storage structures may be either sources or sinks, depending on the time of year or the plant's development.

In places with four seasons, such as Canada, the location of sink and source cells in plants often changes with the seasons (**Figure 7**). In winter, many plants are dormant. A dormant plant does not grow and does not photosynthesize. In the spring, the plant initially depends on carbohydrates stored in its roots or stems, usually as starch. As it begins to grow, the plant breaks down the starch into sugars. As a result, root and stem cells are sources. The upper portions of the plant need energy to grow leaves. The sink cells therefore are mainly at the top of the plant, so that water and dissolved sugars (phloem sap) tend to move upward in the phloem. In summer, the leaves are photosynthesizing and the sugars they produce are stored in roots and stems. Therefore, the source cells are now at the top of the plant, and the phloem sap moves downward.

Figure 7 (a) In early spring, phloem sap moves mainly upward from the roots to the growing shoots. (b) In summer, phloem sap moves mainly downward from mature leaves to the stems and roots.

Figure 8 Source and sink cells may be on the same part of the plant.

Cells in developing seeds and fruits are also sink cells, since they store carbohydrates for the plant embryo. This is one reason why many fruits taste sweet. When a plant produces seeds or fruits, it is still photosynthesizing (**Figure 8**). Sugars must therefore move from source cells in the shoot to sink cells that are also in the shoot.

We can divide the process of sugar transport into three general stages: (i) transport of sugars from source cells to phloem cells, (ii) transport through the phloem, and (iii) transport from phloem cells to sink cells.

From Source to Phloem

After a sugar molecule is produced, it must be transported from the source cell to a phloem cell. The concentration of sugars in phloem cells is generally higher than the concentration in source cells, so sugar transport to the phloem involves active transport across the cell membrane.

The upper part of **Figure 9** shows the transport of sugars from a source cell (a mesophyll cell) into the phloem of an angiosperm. In angiosperms, companion cells transport sugars from source cells to the sieve tube elements. In gymnosperms, sugars are transported from source cells directly into sieve cells, since this is the only cell type in the phloem.

As transport continues, the concentration of sugars in the phloem sap increases. This causes water to be drawn from the xylem cells into the phloem cells by osmosis, which increases the turgor of the phloem cells near the source cells.

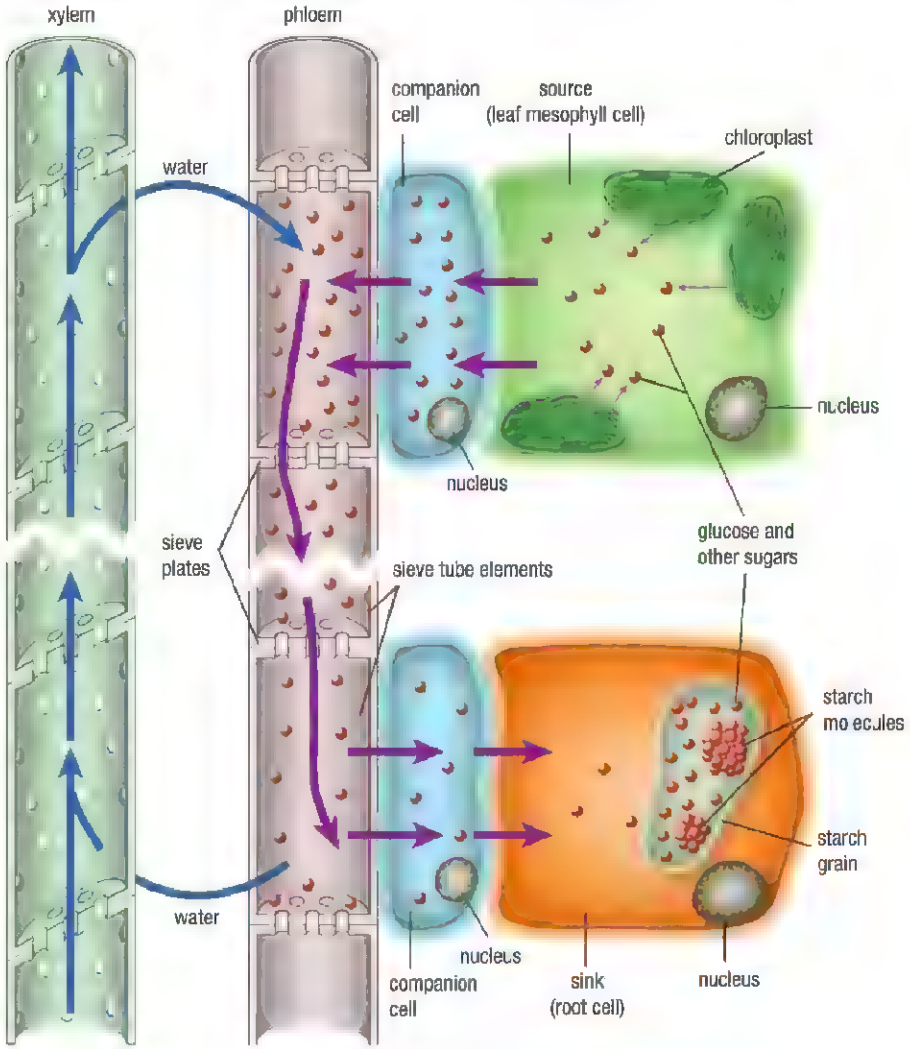


Figure 9 Transporting sugars from a source to a sink cell involves both passive and active transport.

Translocation

The transport of substances for long distances through the phloem is called **translocation**. Unlike xylem tubes, phloem tubes are not hollow, and substances in the phloem sap have to move between living cells. However, sugar molecules can travel more quickly between phloem cells than between other living cell types. Translocation therefore moves sugars quickly enough to supply energy to cells throughout the plant.

translocation long-distance transport of substances through the phloem, particularly glucose

It is not yet entirely clear how translocation is able to move sugars so quickly through the phloem. However, evidence suggests that translocation is driven by the difference in turgor between the phloem cells near source cells and the turgor of phloem cells near sink cells. This difference in turgor pushes the phloem sap in the direction of sink cells.

From Phloem to Sink

Once sugar molecules reach a sink cell, they leave the phloem. The sink cells have a lower concentration of sugars than the phloem cells. The sugars therefore move from the phloem to the sink by passive transport. In angiosperms, the sugars move from the sieve tube elements to the companion cells and then to the sink cells. In gymnosperms, the sieve cells transport sugars directly to the sink cells.

Because sieve tube elements lose sugar molecules, they have a lower concentration of sugars. Water then returns to the xylem from the phloem by osmosis. This maintains the relatively low turgor of phloem cells near the sink and also recirculates the water back into the xylem.

12.5 Summary

- Water and nutrient transport in the xylem tissue involves root pressure, capillary action, and transpiration.
- Nutrients enter root cells by active transport; water enters by osmosis.
- The Casparian strip forces water and nutrients to pass directly through the cells of the endodermis. It also prevents water and dissolved substances from moving back out.
- Water and nutrients move up the xylem tubes by root pressure, capillary action, and transpiration.
- Transpiration is the evaporation of water from the leaves; it is the force that pulls the column of water up the xylem tubes.
- Sugars are actively transported from source to sink in the phloem.
- Phloem sap moves along the phloem tubes as a result of a pressure difference between source cells and sink cells.
- Movement of fluid in the xylem is always upward (or sideways). Movement in the phloem can be upward or downward (or sideways), depending on source and sink locations.

12.5 Questions

1. What is the main driving force for the movement of water in plants? K/U
2. Why must active transport be used to move sugars and other solutes into the phloem? K/U
3. Describe the role of osmosis in movement of solutes in the phloem. K/U
4. During an experiment, a student covers all the stomata of a plant with nail polish, sealing them shut. K/U
   (a) Predict how this would affect water transport.
   (b) How would this affect transport in the phloem?
5. Maple syrup, chicle, and natural rubber all come from the "sap" of trees. Use the Internet and other sources to determine if these products are harvested from the xylem or the phloem. What are the main chemical ingredients in these substances and of what benefit were they to the plant? K/U
6. You purchase some fresh carrots that still have their green leafy tops. Your father tells you to put the carrots in the refrigerator and leave the tops on because that will keep the carrot roots nutritious and crisp. Your mother says she thinks you should cut the tops *off* for the same reason. Who is correct? Explain your reasoning. K/U

12.6 Biology JOURNAL

Biomimicry

ABSTRACT

Biomimicry is a new field in which nature inspires inventions that solve human problems. As researchers learn more about how nature has adapted to similar challenges, and as they share this knowledge with engineers, inventors, companies, and others, unique products are being developed. Many of these products are also environmentally sustainable.

SKILLS HANDBOOK A4

What Is Biomimicry?

Biomimicry is a new field of study that takes designs and processes from nature and applies them to human problems. Researchers, engineers, business people, and inventors work together to solve problems using biomimicry. These people share a belief that the diversity of adaptations in nature can serve as models or inspirations for products or processes to meet our human needs.

Biomimicry came into its own with the book *Biomimicry: Innovation Inspired by Nature*, by Janine Benyus, science writer and biologist (**Figure 1**). In 1998, Benyus co-founded The Biomimicry Guild and Institute, a group that works with companies, inventors, scientists, and educators.

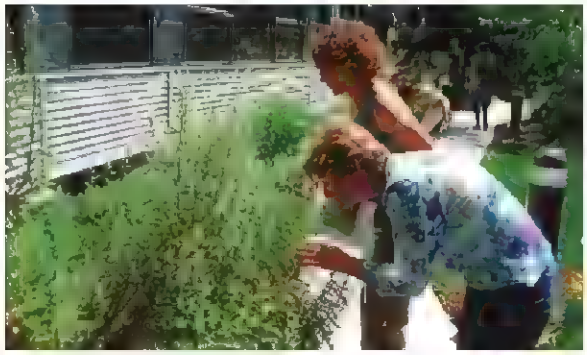


Figure 1 Janine Benyus closely examining a plant

Velcro

Biomimicry has been around longer than the term used to describe this field. One of the best-known examples is Velcro. This now-common material was invented in 1955 by George de Mestral, a Swiss electrical engineer. The idea first came to him in 1948, when he and his dog got covered with burrs while on a hike. At home, de Mestral examined a burr under a microscope and saw that it was covered with tiny hooks that cling to fabric and hair—an ideal plant adaptation for clinging to animals and dispersing the seeds contained within the burr. Inspired, de Mestral began work on a product with hooks (like the burr) on one side and tiny loops on the other, to catch the hooks (**Figure 2**).

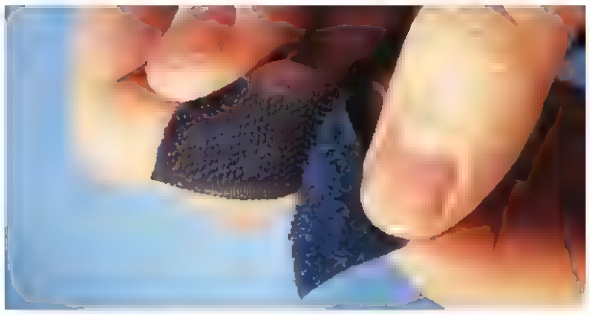


Figure 2 The design of Velcro mimics the adaptations seen in burrs.

Solar Water Pump

When Steven Salter, a professional engineer now living in Victoria, British Columbia, first learned how willow trees transpire water, he envisioned a solar-powered water pump. He reasoned that he should be able to mimic the process of transpiration and collect soil water. By adding a filter, a pump could also purify water from contaminated soils.

Salter's purifying solar water pump can be built with simple materials found in local hardware stores and can be set up in just about any backyard (**Figure 3**).

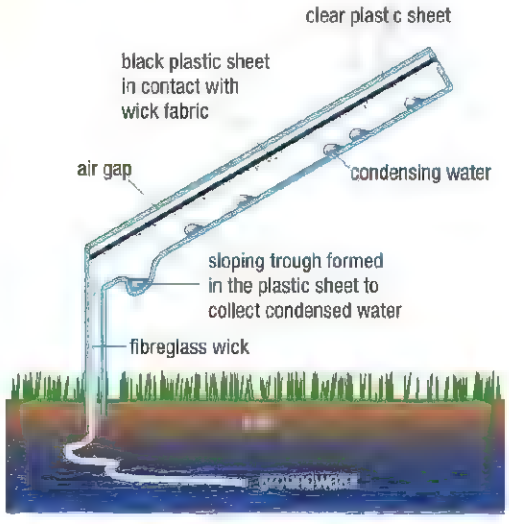


Figure 3 This solar pump design can be made from a number of materials, which makes it relatively inexpensive to produce

Microfluidics

Dr. Abraham Stroock at Cornell University in the United States was also inspired by the vascular tissue of trees. In his case, water transport in plants inspired research on microfluidics. Microfluidics is the study of the movement of tiny volumes of liquid through narrow channels. Dr. Stroock uses hydrogels, soft substances that absorb water, to make thin capillary tubes. Liquid diffuses out of the hydrogel capillaries and into the surrounding material. Since hydrogels are not rejected by the body, hydrogel capillaries could help deliver drugs or remove fluids from wounds, promoting healing

Naturally Clean

Water lilies often live in muddy, marshy environments where they are exposed to dirty water. Dirty leaves cannot photosynthesize as efficiently as clean leaves. However, the cuticle of the water lily has many tiny, raised surfaces that suspend any particles above the leaf. Any dirt particles that do settle get washed off with water droplets that roll off the waxy surface of the leaf (**Figure 4**).

This plant design is being used as a model for new surfaces on solar panels, which must remain clean to maximize the amount of light reaching the photovoltaic cells.

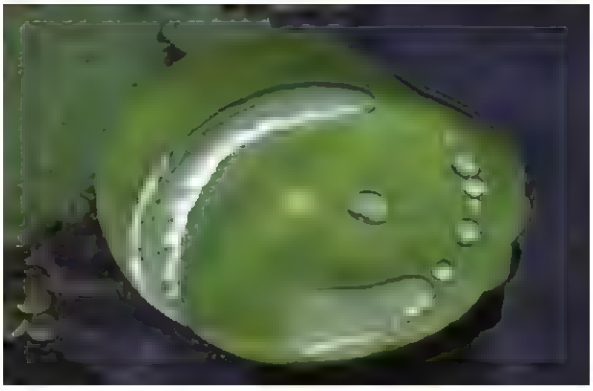


Figure 4 Water lily leaves have surfaces to which virtually nothing will stick

All Kinds of Inspiration

Of course, inspiration for biomimicry does not come only from plants. The V-shape of migrating bird flocks has been applied to jet designs. The shape of wind turbine blades is based on the fins of humpback whales. Shark skin has inspired the material used to make racing swimsuits.

Further Reading

Benyus, J.M. (1997). *Biomimicry: Innovation Inspired by Nature*. New York: Morrow.

Wheeler, T.D., & Stroock, A.D. (2008). The transpiration of water at negative pressures in a synthetic tree. *Nature*, 455, 208 212.

Forbes, P. (2008, August). Self-cleaning materials: Lotus-leaf inspired nanotechnology. *Scientific American*.

GO TO NELSON SCIENCE

12.6 Questions

1. In your own words, explain biomimicry. K/U
2. Would the field of biomimicry be as advanced if scientists had not collaborated with people in other fields of work? Explain, using an example. K/U T/I A
3. Most of the advances in biomimicry require financial backing from companies, which then profit from any product that arises. Do you agree with this process? Why or why not? Explain your reasoning. T/I A
4. Use the Internet and other sources to conduct additional research on one product not mentioned here that arose from biomimicry. Make a flowchart that outlines the steps from problem to inspiration to problem solving for this product. T/I A C
5. These wasps are using chewed up wood and saliva to build their nests (**Figure 5**).

Figure 5
(a) What human-made material mimics this material?
(b) How might the characteristic shape of each egg chamber be of particular benefit?

GO TO NELSON SCIENCE

12.7 Explore Applications in Urban Greening

Improving City Life with Trees

SKILLS MENU

- Researching
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating
- Identifying Alternatives

In Canada, most people live in urban settings. According to Statistics Canada, the urban population is increasing while the rural population is decreasing (**Figure 1**). (A rural area typically has fewer than 150 people per square kilometre.) This trend toward urbanization is a worldwide phenomenon that has significant effects on the number and diversity of trees in the global environment.

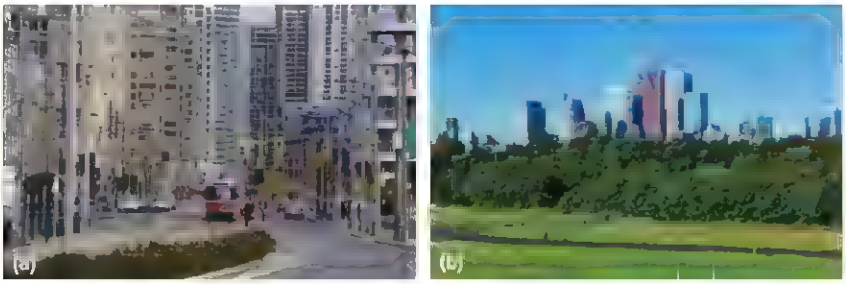


Figure 1 (a) Some parts of a city may have few or no trees. (b) Other parts have many.

Historically, whenever humans settled an area, trees were cut down. Aboriginal peoples cleared land of trees to grow staples such as corn, squash, and beans. European immigrants removed trees on a larger scale to grow crops and also to get lumber for building. However, many farmers, then and today, maintain strips of forest to act as windbreaks to protect soil from wind erosion.

Over time, cities arose from rural towns and villages as the population increased. Cities have many more buildings per square hectare than towns and villages. The most efficient way to construct new buildings is to remove all the trees and other plants first. Therefore, as cities grew, even more trees were removed to make way for more housing, roads, sewers, and industrial areas. Trees have a cooling effect on air temperatures, and the loss of trees and other plants has resulted in cities becoming "urban heat islands" with noticeably higher temperatures than surrounding natural areas. These elevated temperatures contribute to smog formation and air conditioning costs.

In Ontario, the region undergoing urbanization most quickly is the Greater Toronto Area (GTA). Forests of beech, maple, and oak once dominated most of the GTA. At each stage in the transformation from natural forest to rural communities to urban areas, more trees were lost. Today, urban forests are found only in ravines, some parks, and other protected areas. Many homeowners plant species of trees that do not provide habitat for native animal species, which further contributes to loss of biodiversity. Can the negative effects of urbanization on the environment be reduced?

The answer is yes. As our knowledge of the interdependence of Earth's organisms and environment increases, governments, corporations, non-profit organizations, and private citizens are working to increase the tree population in urban areas. We can play a role by planting trees ourselves and convincing our neighbours that planting even one tree can help sustain the environment and make our cities more beautiful.

CAREER LINK

Urban Planner

Urban planners can play a key role in greening urban areas. Urban planners make policies for land use based on environmental, housing, and transportation needs. They may also consult with landowners and community groups about their concerns or plans. To learn more about urban planners,

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The Application

Every neighbourhood has at least a few sites where a tree of some type might be planted to benefit the ecosystem and the people who live there (**Figure 2**). For example, chestnut trees might be planted in an unused area. These trees could provide habitat for birds and insects, food for people, and shade; they could help clean the air of pollutants and reduce the risk of flooding or erosion. They would also help beautify the area, a strategy that has been shown to help maintain people's mental health.

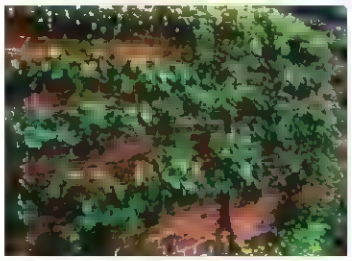

Figure 2 Even a wall can be a site for planting trees, provided there is soil at its base. This apple tree has been carefully pruned so that its branches stay close to the wall.

Your Goal

To create a map or video of your neighbourhood that shows (i) the current location and species of trees already growing and (ii) specific locations that could support the growth of additional trees and to use your map or video to convince others that there is lots of opportunity to green your community

Research

SKILLS HANDBOOK A5

Use the Internet and other sources to answer the following questions:

(a) How are the existing trees beneficial to your neighbourhood? Consider benefits for the environment (for example, habitat, erosion control) and for people (for example, fruit, shade).

(b) What problems in your neighbourhood could be helped by planting trees? For example, if you live near a waterway, planting trees could reduce flooding. If you are in an area that has few grocery stores, fruit trees could help people improve their diets. You may need to check news publications to identify issues in your community.

(c) What problems might adding trees cause? Consider environmental and human problems. For example, creating habitat might cause some organisms to be harmed by traffic or attract species that are considered a nuisance. Additional trees might reduce visibility on roadways, increasing the risk of traffic accidents.

(d) What levels of government, corporations, or non-profit groups are active in planting trees or improving neighbourhoods in your area?

WEB LINK

Many groups are involved in greening cities. To find out what they are doing and if they could help your community,

GO TO NELSON SCIENCE

Summarize

Collect all the information gathered by your group. From your map or video, choose at least two areas from your neighbourhood that you think would be good candidates for tree planting. Create a benefit–cost table for additional trees in each area.

UNIT TASK BOOKMARK

You may use your skills in choosing the best way to present information to a specific audience in the Unit Task.

COMMUNICATE

Decide as a group whom you would approach to make a case for more trees in your neighbourhood. Create a presentation in a style appropriate for that audience. In your presentation, include the map or video you created.

Plan for Action

Trees in urban areas have a shorter life span than trees in rural or uninhabited areas (**Figure 3**). Their leaves become coated with particulates from the air, making photosynthesis less efficient. Their roots often run under roads, where the soil is highly compacted and has few nutrients. Toxins, including those from vehicles and household chemicals, can stunt their growth or kill them entirely. They are also more likely to need water, since urban areas are warmer than rural areas and trees seldom get watered if they are not on private property. Make a plan to help the trees on your school property stay healthy. Present your plan to the rest of your class. Maybe you can form a club to help the trees keep helping your school community!

Figure 3

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CHAPTER 12 Investigations

Investigation 12.2.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Leaf Structure in Vascular Plants

The leaves of vascular plants share some common characteristics, but they also have a variety of adaptations to the environments in which they live. In this activity you will observe prepared slides of cross sections of the leaves of angiosperm plants that are adapted to different environmental conditions. You will then relate the structural modifications of the leaves to the conditions in which the plants grow.

Purpose

To compare the structure of leaves, using prepared slides, of various angiosperm plants that are adapted to different environments

Equipment and Materials

- microscope
- prepared slides of leaf cross-sections (xerophytes, mesophytes, and hydrophytes)
- unlined paper
- pencil

Procedure

SKILLS HANDBOOK A2.4, A3.2, A3.3

1. Obtain prepared slides of leaves from three different plants: a xerophyte, a mesophyte, and a hydrophyte. Xerophytes live in arid, dry environments, and mesophytes live in more moderate environments. Hydrophytes are aquatic plants.
2. At the top of a clean sheet of unlined paper, record the information for the first leaf type.
3. Use an appropriate magnification to view the internal structure of the leaf and make a biological drawing. Your drawing should highlight the general arrangement of cells, including the epidermal, palisade, and spongy mesophyll layers. Note the presence of vascular bundles and the location of guard cells.
4. Label your drawing.
5. Record any adaptations you observe that might help the plant survive. For example, you might observe aerenchyma in the leaf of a hydrophyte plant (**Figure 1**) or a tightly packed mesophyll layer in a xerophyte plant (**Figure 2**).

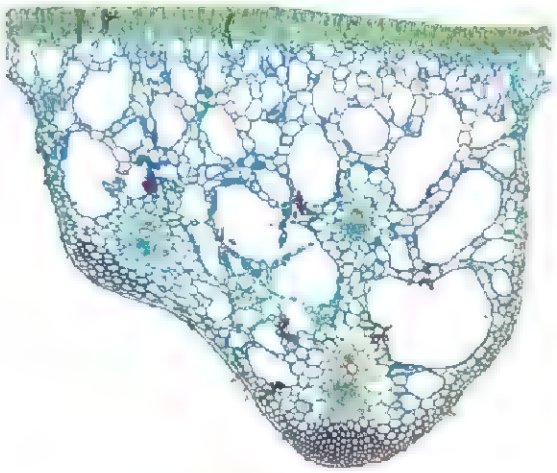


Figure 1 Cross-section of a water lily leaf (a hydrophyte)

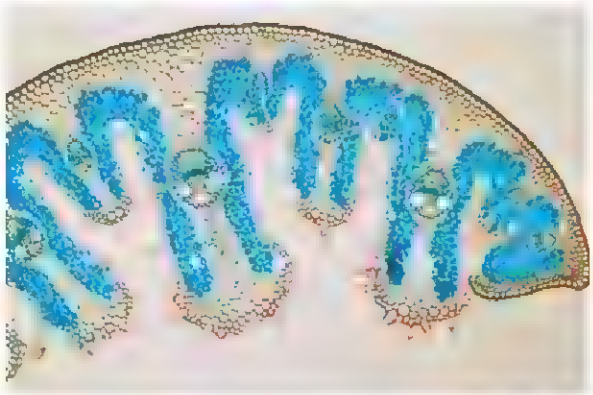


Figure 2 Cross-section of part of a marram grass leaf (a xerophyte)

Analyze and Evaluate

(a) Did you observe any adaptations that would help maximize photosynthesis? If so, describe how it would affect this process. T/I A

(b) Describe any structural specializations in the slides you observed that you predict are related to

(i) the plant's particular environment

(ii) protection from herbivores or pathogens

(iii) conservation of water K/U A

(c) For each specialization you described for (b), explain how the structural specialization would achieve the function you predicted. T/I A

Apply and Extend

(d) You can make an image of the surface of a leaf by coating the leaf with nail polish, waiting for the polish to dry, and then peeling off the dried polish. The positions of the stomata on the leaf surface can then be observed under a microscope. Using this method, write a procedure to compare the stomata on the surface of leaves of a terrestrial plant and an aquatic plant. Include a prediction relating the number and position of the stomata to the type of plant. K/U T/I A

Investigation 12.3.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Comparing Monocot and Eudicot Stem Cross-Sections

Toluidine blue O (TBO) is a stain commonly used to observe the cells in plant tissues. TBO turns greenish blue or bright blue in the presence of lignin. Lignin is found in much greater quantities in the walls of xylem cells than in other cell types. It stains other cell wall components pinkish purple. In this investigation you will prepare cross-sections of monocot and eudicot stems and stain the sections with TBO. You will then observe the stained cross-sections under a microscope and record your observations in a biological drawing.

Purpose

To observe TBO-stained cross-sections of monocot and eudicot stems and record your observations in labelled biological drawings

Equipment and Materials

- Petri dish
- single-edged razor blade
- small paint brush
- microscope slide and cover slip
- TBO stain in dropper bottle
- distilled water in dropper bottle
- paper towels
- young monocot seedling (such as corn)
- young eudicot seedling (such as bean)

Procedure

SKILLS HANDBOOK A2.4, A3.2, A3.3

1. Obtain a Petri dish and half-fill it with water.
2. Obtain a stem from a young monocot seedling (such as a corn seedling). Place the stem in the Petri dish.
3. To make cross-sections of the stem, first hold the stem firmly against the bottom the Petri dish, using the thumb and forefinger of one hand. Carefully pick up the blunt side of the single-edged razor blade with your other hand. Carefully make 10 to 15 thin cuts at right angles to the stem. Make your cross-sections as thin as possible.

Be careful using the razor blade. Make sure to handle it only by the non-sharp edge and to cut away from yourself and any person nearby.

4. Choose two or three very thin cross-sections. Using the paint brush, gently pick up the cross-sections and place them on a clean microscope slide.
5. Place a drop of TBO stain on the cross-sections on the slide. Gently lower a cover slip over the cross-sections, being careful not to trap any air underneath.

TBO can stain clothes and skin.

6. Wait 2 min. Then, using the dropper, place a drop of distilled water against one edge of the cover slip.
7. Place a small piece of paper towel against the opposite edge of the cover slip. Allow the paper towel to take up liquid. This step absorbs any excess TBO.
8. Observe the cross-sections under the microscope.
9. On a clean sheet of unlined paper, create a biological drawing of a representative portion of the stem.
10. Locate, draw, and label as many of the following tissues as possible: xylem, phloem, vascular bundles, ground tissue epidermis. Refer to page 553 and **Figure 1(a)** to help you.

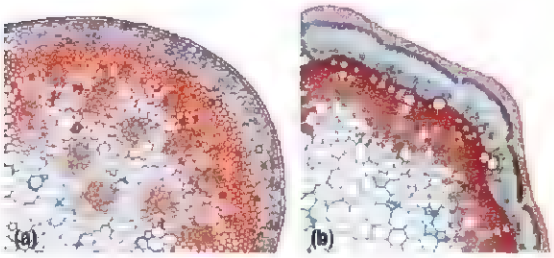


Figure 1 Sample images of stem cross-sections of (a) a monocot and (b) a eudicot.

11. Repeat Steps 1 to 10 using a young eudicot seedling. Refer to page 553 and **Figure 1(b)** to help you.

Analyze and Evaluate

(a) Based on your observations,

(i) what are the major distinguishing features of the monocot stem?

(ii) what are the major distinguishing features of the eudicot stem? K/U T/I

Apply and Extend

(b) About 90 % of Canada's sugar is refined from imported sugar cane. **Figure 2** shows a cross-section of a sugar cane stem. K/U T/I

(i) Is sugar cane a monocot or a eudicot?

(ii) In which cell type(s) do you predict that sugar is stored in these stems? Explain why.

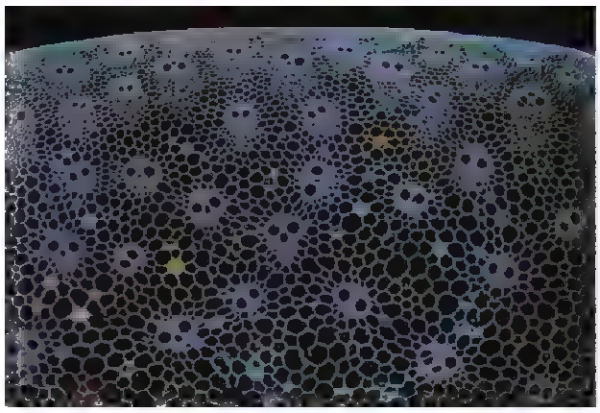


Figure 2 Stained cross-section of sugar cane

Investigation 12.4.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Comparing Monocot and Eudicot Root Cross-Sections

In order to transport materials in the plant body, vascular tissue must form continuous columns throughout the roots, stems, and leaves. In this investigation you will observe the arrangement of xylem and phloem in the roots of monocots and eudicots.

Purpose

To observe prepared cross-sections of monocot and eudicot roots and record your observations in labelled biological drawings

Equipment and Materials

- microscope
- prepared slides of monocot and eudicot roots
- unlined paper

Procedure

SKILLS HANDBOOK A2.4, A3.2, A3.3

1. Obtain prepared slides of root cross-sections of a monocot species and a eudicot species.
2. Choose a slide to view. Record the information on the label of the slide on a clean sheet of unlined paper. This information may include the name of the species, the type of section (such as cross-section), and the name of any stain used.
3. Using the proper technique and a suitable magnification, observe the root cross-section.
4. Create a labelled biological drawing of the root cross-section. Locate and identify the following: xylem, phloem, parenchyma, root hairs, epidermis, and endodermis. Refer to page 559 and **Figure 1(a)** and **(b)** to help you identify these.
5. Repeat Steps 2 to 4 for the other root type.

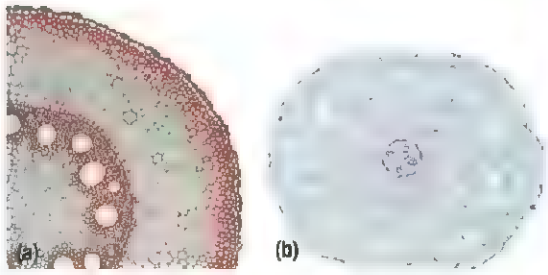


Figure 1 Sample images of root cross sections of (a) a monocot (b) a eudicot

Analyze and Evaluate

(a) Briefly describe how you identified the various cell types in the root cross-sections. T/I A

(b) In a table or a chart, summarize the differences you observed between monocot and eudicot roots. T/I C

Apply and Extend

(c) There are no major root crops harvested from woody plants. Why is this not surprising? A

CHAPTER 12 SUMMARY

Summary Questions

1. Create a study guide based on the Key Concepts listed at the beginning of the chapter, on page 540. For each point, create three or four subpoints that provide further information, relevant examples, explanatory diagrams, or general equations.
2. Return to the Starting Points questions at the beginning of the chapter, on page 540. Answer these questions using what you have learned in this chapter. Compare your answers with those that you gave at the beginning of the chapter. How has your understanding changed? What new knowledge and skills do you have?

Vocabulary

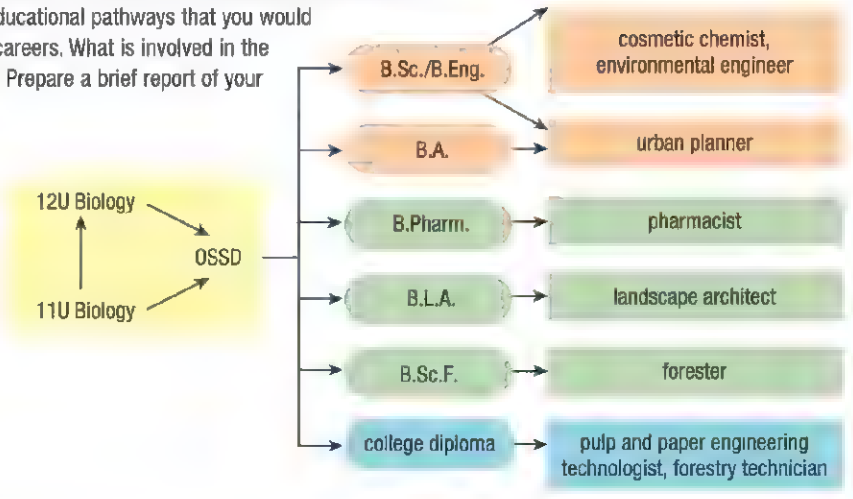
carbohydrate (p. 542)
meristematic tissue (meristem) (p. 543)
cotyledon (p. 544)
chloroplast (p. 547)
photopigment (p. 547)
blade (p. 547)
petiole (p. 547)
venation (p. 548)
mesophyll (p. 548)
palisade mesophyll (p. 548)
spongy mesophyll (p. 548)
stoma (p. 548)
guard cell (p. 548)
aerenchyma (p. 549)
psychotropic (p. 551)
herbaceous (p. 552)
woody (p. 552)
vascular bundle (p. 553)
vascular cambium (p. 553)
bark (p. 554)
cork cambium (p. 554)
tracheid (p. 555)
vessel element (p. 555)
perforation plate (p. 555)
sieve cell (p. 555)
sieve tube element (p. 555)
sieve plate (p. 555)
companion cell (p. 555)
taproot system (p. 558)
lateral root (p. 558)
root hair (p. 558)
fibrous root system (p. 558)
root cap (p. 559)
root cortex (p. 559)
endodermis (p. 559)
Casparian strip (p. 559)
vascular cylinder (p. 559)
tuberous root (p. 560)
adventitious root (p. 561)
root pressure (p.566)
capillary action (p. 566)
transpiration (p. 567)
turgor (p. 567)
source (p. 568)
sink (p. 568)
translocation (p. 569)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or postgraduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select two careers related to the anatomy, growth, and function of plants that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



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CHAPTER 12 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which of the following is true of plants? (12.1) K/U
   (a) Since they cannot move away from herbivores, plants have developed other ways to protect themselves.
   (b) Carbon dioxide is the main source of the chemical energy plants need for development.
   (c) All plants absorb nutrients from water in the soil.
   (d) A plant can die only from too little water, never from too much.
2. A molecule that contains only atoms of carbon, oxygen, and hydrogen is a
   (a) cotyledon
   (b) petiole
   (c) chloroplast
   (d) carbohydrate (12.1) K/U
3. Leaf cells absorb energy from sunlight in an organelle called a
   (a) cotyledon
   (b) petiole
   (c) chloroplast
   (d) carbohydrate (12.2) K/U
4. Which is true of most gymnosperms? (12.2) K/U
   (a) They do not lose their leaves in cold climates.
   (b) To prevent water loss, their leaves are small.
   (c) Their leaves produce chemicals to prevent their cells from freezing.
   (d) all of the above
5. Why are woody stems able to grow thicker over the years? (12.3) K/U
   (a) Woody stems have vascular bundles.
   (b) Woody stems have vascular cambium.
   (c) Woody stems are photosynthetic.
   (d) Woody stems are herbaceous.
6. Which of the following root systems is composed of a large, thick root? (12.4) K/U
   (a) fibrous root system
   (b) taproot system
   (c) lateral root system
   (d) none of the above
7. The root cortex ends at the
   (a) vascular cylinder
   (b) root hair
   (c) root cap
   (d) endodermis (12.4) K/U
8. Which of the following helps water and dissolved nutrients move upward against gravity? (12.5) K/U
   (a) root pressure
   (b) capillary action
   (c) transpiration
   (d) all of the above
9. Which of the following is true of dormant plants? (12.5) K/U
   (a) They grow very slowly.
   (b) They do not photosynthesize.
   (c) Most are dormant only when it is very warm.
   (d) They die shortly after dormancy.
10. One of the best-known examples of biomimicry is
    (a) Velcro
    (b) the automobile
    (c) indoor plumbing
    (d) electricity (12.6) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

11. Glucose is a carbohydrate. (12.1) K/U
12. The seeds of angiosperm species always contain only one cotyledon. (12.1) K/U
13. Dicots are classified into one group. (12.1) K/U
14. The veins of leaves contain the vascular tissue. (12.2) K/U
15. The arrangement of the veins within a leaf is called its venation. (12.2) K/U
16. In monocot stems, vascular bundles are arranged in a ring. (12.3) K/U
17. Herbaceous stems have a more complex structure than woody stems. (12.3) K/U
18. Sieve cells are only found in angiosperms. (12.3) K/U
19. All stems hold plants upright. (12.3) K/U
20. The main role of plant roots is to absorb carbohydrates. (12.4) K/U
21. Roots can be used to help control erosion. (12.4) K/U
22. Translocation is responsible for pulling water molecules from the roots to the leaves. (12.5) K/U
23. In plants, sugars may be produced by photosynthesis or from breaking down carbohydrates in storage organs, such as tubers. (12.5) K/U
24. Dirty leaves photosynthesize more efficiently than clean leaves. (12.6) K/U

To do an online self-quiz,
GO TO NELSON SCIENCE

CHAPTER 12 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. Glucose is a
   (a) plant
   (b) protein
   (c) carbohydrate
   (d) cotyledon (12.1) K/U
2. Tea plants contain several chemical compounds, including tannins and caffeine. What function do both tannins and caffeine perform for tea leaves? (12.2) K/U
   (a) They both protect the plant from herbivores.
   (b) They both provide the rich green colour.
   (c) They both perform water absorption.
   (d) all of the above
3. What function do guard cells perform? (12.2) K/U
   (a) They carry out photosynthesis and gas exchange.
   (b) They control the opening and closing of a stoma.
   (c) They prevent cells from freezing
   (d) They provide structural support to the leaf.
4. Herbaceous plants have stems that do not contain
   (a) water
   (b) oxygen
   (c) cells
   (d) wood (12.3) K/U
5. What is the layer of meristematic cells in the vascular tissue that divides to form new xylem and phloem cells? (12.3) K/U
   (a) vascular cambium
   (b) vascular bundle
   (c) cork cambium
   (d) perforation plate
6. The main role of plant roots is to
   (a) protect the plant from herbivores
   (b) raise and support the leaves
   (c) take in carbohydrates
   (d) absorb water and nutrients (12.4) K/U
7. By what process does water enter the root cells of a plant? (12.5) K/U
   (a) photosynthesis
   (b) active transport
   (c) osmosis
   (d) none of the above
8. What is the study of the movement of tiny volumes of liquid through narrow channels called? (12.6) K/U
   (a) biomimicry
   (b) microbiology
   (c) micromimicry
   (d) microfluidics

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

9. The body of every vascular plant consists of an underground root system and an above-ground shoot system. (12.1) K/U
10. The blade of the leaf is attached to the stem by a stoma. (12.2) K/U
11. The spines on a cactus are modified leaves that perform photosynthesis. (12.2) K/U
12. A vascular bundle is a long, continuous strand of vascular tissue that consists of xylem and phloem. (12.3) K/U
13. The roots of all plant species have the same general structure. (12.4) K/U
14. Unlike other living cells, plant cells do not use glucose and other sugars as a source of energy. (12.5) K/U
15. A solar water pump mimics photosynthesis. (12.6) K/U

Write a short answer to each question.

16. List the three atoms that make up a glucose molecule. (12.1) K/U
17. Vascular plants have three main non-reproductive organs. List all three. (12.1) K/U
18. What have recent DNA studies revealed about the placement of all species with two cotyledons into one group? (12.1) K/U
19. What pigment gives leaves their characteristic green colour? (12.2) K/U
20. Why are dark green leafy vegetables, such as spinach, especially nutritious? (12.2) K/U
21. List three ways in which humans use leaves. (12.2) K/U
22 Why are woody stems able to grow thicker than herbaceous stems over time? (12.3) K/U
23. (a) What is a companion cell?
    (b) What group of vascular plants have this type of cell? (12.3) K/U

24. Name the two basic types of root systems. (12.4) K/U
25. What are adventitious roots? (12.4) K/U
26. Most of the roots eaten by humans are specialized for what purpose? (12.4) K/U
27. List the three stages of water and nutrient transport. (12.5) K/U
28. What do water molecules and nutrients encounter once they reach the endodermis? (12.5) K/U
29. Define transpiration. (12.5) K/U
30. What common material did Swiss electrical engineer George de Mestral invent, and what did he base his invention on? (12.6) K/U

Understanding

31. All organisms face change in their environment. For plants, it is especially important that they be able to adapt to change in their environment. Explain why this is so. (12.1) K/U
32. Vascular plants have three main non-reproductive organs. These organs are primarily composed of three tissue types: dermal tissue, vascular tissue, and ground tissue. Create a table similar to **Table 1**. Use your knowledge from the chapter to fill in the "Description" and "Role" columns of your table. (12.1) K/U

Table 1 Descriptions and Roles of Plant Tissues

Tissue	Description	Role
dermal tissues		
vascular tissues		
ground tissues		

33. Although vascular plants come in a variety of shapes and sizes, the body of every vascular plant has the same basic design. Describe and/or draw the physical appearances of two very different vascular plants to demonstrate that they have the same basic design. (12.1) T/I
34. Leaves may play various roles in the plant, including photosynthesis, gas exchange, storage, and protection from herbivores. Describe how leaves might help a plant defend itself against herbivores. (12.2) K/U
35. Though plants exist on land in virtually every region and climate on Earth, some types and species of plants are better suited to specific regions and climates than others. Explain why, in many parts of Canada, gymnosperms have an advantage over plants with large, thin leaves. (12.2) K/U
36. In aquatic vascular plants, such as the water clovers shown in **Figure 1**, the internal mesophyll is replaced with aerenchyma. (12.2) K/U
    (a) What is aerenchyma?
    (b) Explain the purpose of aerenchyma in aquatic plants.

Figure 1 Water clover

37. Describe how the general structure of a leaf helps it carry out its roles in photosynthesis and gas exchange. (12.2) K/U
38. Depending on the species of plant, leaves can play varying roles. (12.2) T/I
    (a) Explain what is meant by the phrase "leaf specialization."
    (b) Give an example of a species of plant that has leaves that play a specialized role.
39. Woody stems are more complex structures than herbaceous stems. On a cross-section of a woody stem, growth rings are visible. (12.3) K/U C
    (a) Draw a simple cross-section of a woody stem, showing its growth rings.
    (b) Label the different parts of the stem, including the growth rings.
    (c) What roles do the seasons play in the formation of growth rings, and how do the different seasons change the appearance and makeup of xylem cells?
40. Though the leaf is the part of the plant that carries out photosynthesis, stems do play a part in this process. Describe the role that stems play in photosynthesis. (12.3) K/U

41. Stems of plants have several important roles. In some plant species, such as most cactus species, the standard roles their stems play have been modified. (12.3) K/U A
    (a) In what ways are the roles of cactus stems modified?
    (b) Explain how the climates in which most cactus species exist made these modifications necessary.
42. All stems connect the vascular tissue of the plant shoot and root, but not all stems hold plants upright. Examples of this can be found in species of vines. (12.3) K/U
    (a) Explain how vine stems support their leaves.
    (b) Give one example of a vine that has a woody stem and one example of a vine that has a herbaceous stem.
43. The roots of over 80 % of plants have a mutualistic relationship with mycorrhizal fungi. (12.4) K/U
    (a) Define what it means to have a mutualistic relationship with another organism.
    (b) Describe the mutualistic relationship between roots and mycorrhizal fungi.
44. Root specializations may exist to help a plant perform tasks other than water and nutrient absorption. Look at **Figure 2**. (12.4) K/U
    (a) What type of root is pictured?
    (b) What specialized role does this type of root perform?

Figure 2

45. The region surrounding Lake Temagami, northeast of Sudbury, is home to many hectares of forests. (12.5) K/U
    (a) What makes the forests of this region so special?
    (b) Although the trees in these forests are so special, describe how they are they just like almost all vascular plants.
46. Explain how an adequate amount of water prevents a plant from wilting, and explain why and how wilting occurs. (12.5) K/U
47. The process of sugar transport has three general stages: (i) transport of sugars from source cells to phloem cells, (ii) transport through the phloem, and (iii) transport from phloem cells to sink cells. Briefly describe each stage. (12.5) K/U
48. Explain how a solar-powered water pump is a good example of biomimicry. (12.6) T/I

Analysis and Application

49. Unlike many other organisms, plants are immobile. To cope with this, each plant species has specific adaptations for a particular range of environmental conditions. Predict the adaptations a species of plant might have if it lived in an environment that has short days with little sunlight during winter, such as northern Canada. (12.1) T/I A
50. Virtually all plant species have some way of protecting themselves against herbivores. Yet there exist many thriving species of herbivores across the globe. Demonstrate how these two realities can coexist (12.1) T/I A
51. Leaves are important to the plants on which they grow. They are equally important to almost every other living organism on Earth. Demonstrate how leaves are so important to other living things, and predict what Earth would be like without leaves. (12.2) T/I A
52. Based on what you have learned about leaf specializations, describe a scenario in which leaves have no ability to perform any roles other than photosynthesis. If leaves on a plant could perform only photosynthesis and gas exchange, what would that mean for the plant? Choose one specialized function and describe how an entire ecosystem might be affected by its absence. (12.2) T/I C A
53. Choose a leaf from a species of plant that you have read about in the text and demonstrate how the specializations it uses to protect itself from herbivores can be used by humans for other purposes. (12.2) K/U A
54 Many cultures around the world use leaves as sources of food and to add flavour to food. (12.2) K/U T/I A
    (a) Select three types of leaves and describe the ways in which various cultures use them.
    (b) Hypothesize as to why different cultures use different types of leaves in their cuisines.

55. Examine the micrograph in **Figure 3**. Is this a cross-section of a monocot or a eudicot stem? Explain. (12.3) T/I A

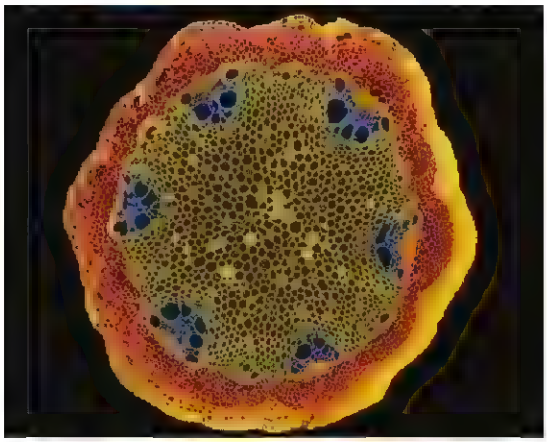

Figure 3

56. The wide diversity in types of stems is partly because some species have herbaceous stems and some have woody stems. (12.3) T/I A
    (a) Compare and contrast herbaceous stems and woody stems in terms of their anatomy and appearance.
    (b) Provide two examples of plant species with herbaceous stems and two examples of plant species with woody stems.
57. It is clear that the forestry and pulp and paper industries contribute greatly to the Canadian economy. What are the social and environmental costs associated with these industries? Discuss what it might mean for Canada if logging became unsustainable. (12.3) T/I C A
58. Humans have found many uses for a wide variety of structures and chemicals produced by vascular plant stems. (12.3) K/U T/I A
    (a) Identify two structural and/or chemical uses of plant stems.
    (b) In each example, explain why the leaves and roots of this plant could not be used in place of the stem.
59. Compare and contrast the two types of root systems. Describe the characteristics of each. (12.4) A
60. Roots are usually hidden from view. Using your knowledge of root systems and what roles roots play, assess why root systems must be "hidden from view." (12.4) K/U T/I
61. Suppose you were an engineer hired by a private landowner to correct an erosion problem on a large stretch of cleared hillside. The erosion has been going on for many years. Knowing what you now know about the potential benefits of roots and root systems, devise a plan for saving this hillside from further erosion. Be creative, but use facts from your readings. (12.4) T/I C A
62. If you are out working in your garden, you may have noticed that the unwanted plants or "weeds" you are trying to pull out offer different levels of resistance. (12.4) K/U T/I A
    (a) Suggest how the different types of root systems make some plants more difficult to pull or dig out of the ground than others.
    (b) For each type of root system, suggest different strategies that you might use to make your work easier.
63. The roots of some plants produce chemicals that harm other plants. One example of this is the black walnut root, which secretes a toxin that inhibits the growth of other plants. Establish how this specialization can be beneficial to the plant and suggest how it could also be detrimental to the plant. (12.4) K/U T/I
64. (a) Identify which part of the plant the micrograph shown in **Figure 4** comes from.
    (b) Justify your answer.
    (c) Is it from a monocot or a eudicot? Explain. (12.4) K/U T/I

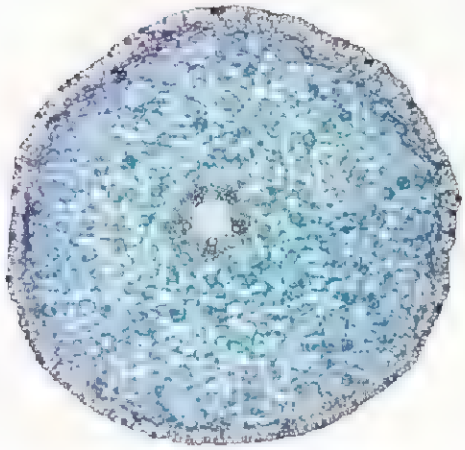

Figure 4

65. Many of the vegetables eaten by humans are roots. Most of the roots we eat are taproots, such as carrots, turnips, beets, cassava, and taro. (12.4) K/U T/I A
    (a) Why are taproots more appetizing to humans than other types of roots?
    (b) What is it about the growth and chemical structure of taproots that makes many of them more desirable to eat when they are young, rather than old?
66. Unlike water and nutrients, which always move up the plant, sugars can move up or down the plant. The direction in which sugars are transported depends on the location of source cells relative to sink cells. (12.5) K/U T/I
    (a) Explain how in places with four seasons, such as Canada, the direction of transport varies with the seasons.
    (b) Suggest how the direction of transport could play a role in causing leaves to change colour in autumn.
67. As researchers learn more about how nature works, and as they share this information with engineers, inventors, companies, and others, unique products are being developed. (12.6) T/I A
    (a) Describe an adaptation in nature that you have observed or been made aware of.
    (b) Hypothesize as to how this adaptation might be applied to an invention.
68. Though biomimicry is a relatively new field, taking designs and processes from nature and applying them to human problems is something that humans have done for many years. Working backward, think of a human invention that mimics something in nature. Report on how your object or design resembles something natural (for example, a submarine and a blue whale). Cite specific details in your report. Be creative. (12.6) T/I C A

Evaluation

69. Carnivorous plants meet some of their nutritional needs by digesting other organisms, especially insects. Most carnivorous plants grow in very moist, nutrient-poor, acidic areas, such as bogs. Draining and converting such areas to agricultural land is causing a decline many species of carnivorous plants. Predict this human activity would affect the ability of a carnivorous plant to meet its nutritional needs. Briefly outline your reasoning. (12.1) K/U T/I A
70. List three different uses humans have for plants. For example, one use is to make textiles. Make a three-column table and place your three uses in the left column. In the middle column, name as many plants as you can think of that are used for each use. In the third column, briefly describe how life for humans would be affected if none of the plants in column 2 existed for the use in column 1. (12.1) K/U T/I A
71. Tea has had a profound effect on many cultures. In Japan and China there are elaborate tea ceremonies. The popularity and relative scarcity of tea once made it a very valuable commodity. As a result, tea was initially consumed mainly by the upper classes of societies. Trading in tea also became big business. (12.2) K/U T/I A
    (a) Think of another plant leaf that did, or still does, command similar importance throughout the world.
    (b) What social, economic, and political effects did or does this plant leaf have?
    (c) Suggest how an absence of this leaf might have changed, or may change, the societies that gave or give it such importance.
72. The general structure of a leaf helps it carry out photosynthesis and gas exchange. Using your knowledge of photosynthesis, design a plant and leaves that, together, allow the plant to maximize the amount of photosynthesis. Give specific details about your plant and its leaves that support your claim of photosynthetic efficiency. (12.2) K/U T/I A
73. Refer to the picture of the African baobab tree in **Figure 5**. Use your knowledge of stems to answer the following questions. (12.3) K/U T/I A
    (a) How is this tree different from many Canadian tree species?
    (b) What stem specialization do you think this plant exhibits?
    (c) Suggest the climate in which the tree usually grows, which makes this specialization necessary.

Figure 5

74. In northern Ontario, tree stems are harvested as the raw material for making pulp and paper. Recently, the popularity of email and online papers has risen dramatically. What do you think the environmental, social, and economic effects of this rise may be in northern Ontario? T/I A

75. Look at the micrograph in **Figure 6**. (12.3) K/U T/I A
    (a) What type of cells do you think these are? Explain your reasoning.
    (b) What tissue are they a part of?
    (c) How does their structure help them perform their function?

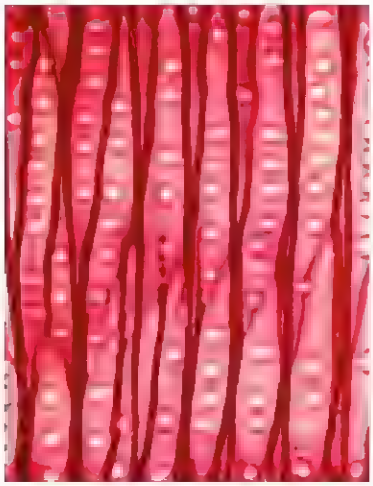

Figure 6

76. Humans have found many and varied uses for plant stems. You may not even think about how many items made from plant stems are a part of your everyday life. (12.3) K/U T/I A
    (a) Look around you. How many items made from plant stems can you see from where you are sitting? List as many as possible.
    (b) Choose two of the items from your list and consider what life would be like without them. How would it be different? Could any of these items be made from other materials?
77. Make an argument that the root system is the most important part of the plant. In your argument, use your knowledge of plants and their root systems to support your argument. Be persuasive. (12.4) K/U T/I C
78. Based on what you know about the transport of sugars in plants and how seasons can affect the direction in which sugars are transported, predict what might happen if a forest of Canadian trees were transplanted to a region whose warm climate varies very little with the seasons, such as central Africa or northern Brazil. Describe the changes that might occur in the transplanted trees. (12.5) K/U T/I A
79. Think of an environmental concern or a global problem that exists today. Use biomimicry to create a device or process that solves the environmental problem. Be sure to base your design on an example from nature. (12.6) T/I C A

Reflect on Your Learning

80. What aspect of leaves did you find the most interesting? Explain. T/I
81. Were you surprised to learn of the detailed structure and functions of stems? Explain why or why not. T/I
82. What root specializations did you find the most fascinating or surprising? T/I
83. Has anything you have learned about the human uses of various plants surprised you? Explain why or why not. T/I
84. Knowing what you now know about plants, has your opinion about them changed at all? In what ways? T/I

Research

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85. Research the Canadian Boreal Initiative and the sustainable use of the boreal forest. What are the goals of this initiative? How is the boreal forest being used in a sustainable way? Write a report on your findings. Present your report to your classmates. T/I C A
86. Peter Francis Stevens has contributed a great deal of knowledge to the field of angiosperm phylogeny. Gather as much information as you can on this important scientist and his contributions. Write a report on your findings. Present your report to your classmates. T/I C A
87. Research the medicinal uses of plant leaves and roots. Write a report on the different types of medicines and treatments derived from plant leaves and roots that you have discovered. Include any very recent medical breakthroughs attributed to leaves or roots of plants. Present your report to your classmates. T/I C A
88. Research how plants are being used to clean waste water from fish farms in order to reduce pollution. Explore the types of plants used and the specific roles these plants play. Write a report on your findings. Present your report to your classmates. T/I C A

CHAPTER 13

Succession, Reproduction, and Sustainability

KEY CONCEPTS

After completing this chapter you will be able to

- discuss how different societies or cultures have used plants in a sustainable way
- design and conduct an inquiry to determine the factors that affect plant growth
- describe various techniques of plant propagation
- compare and contrast monocot and eudicot plant structures and evolutionary processes
- explain the reproductive mechanisms of plants in natural reproduction and artificial propagation
- describe the various factors that affect plant growth
- explain the process of ecological succession, including the role of plants in maintaining biodiversity

How Do Plants Respond to Changes in the Environment?

Imagine you and your friends are putting on a presentation to new Canadians about appropriate outdoor clothing for life in Canada. Some of your audience have never seen snow and do not know how to dress for a Canadian winter. Others might believe that Canada is cold year round. What seasonal changes in the outdoor environment would you need to consider?

The plants in Canada must also survive these seasonal changes. For example, the marvellous fall colours of deciduous trees in parts of Canada are due in part to a leaf-shedding adaptation that helps protect the plant from freezing damage and water loss during the winter. Non-deciduous trees, such as conifers, are adapted to cold winter weather in other ways. Conifers have needles that stay on the tree year round. These needles have a thick, waxy cuticle that helps prevent freezing damage. Plants in other parts of the world must also be able to respond to cyclical changes in their environments, such as wet and dry seasons. Plants also have to respond to sudden changes in the environment, such as the rain and temperature change of a sudden thundershower. Humans can usually run indoors or put on a coat when such changes occur, but plants must be able to respond to environmental changes while staying put.

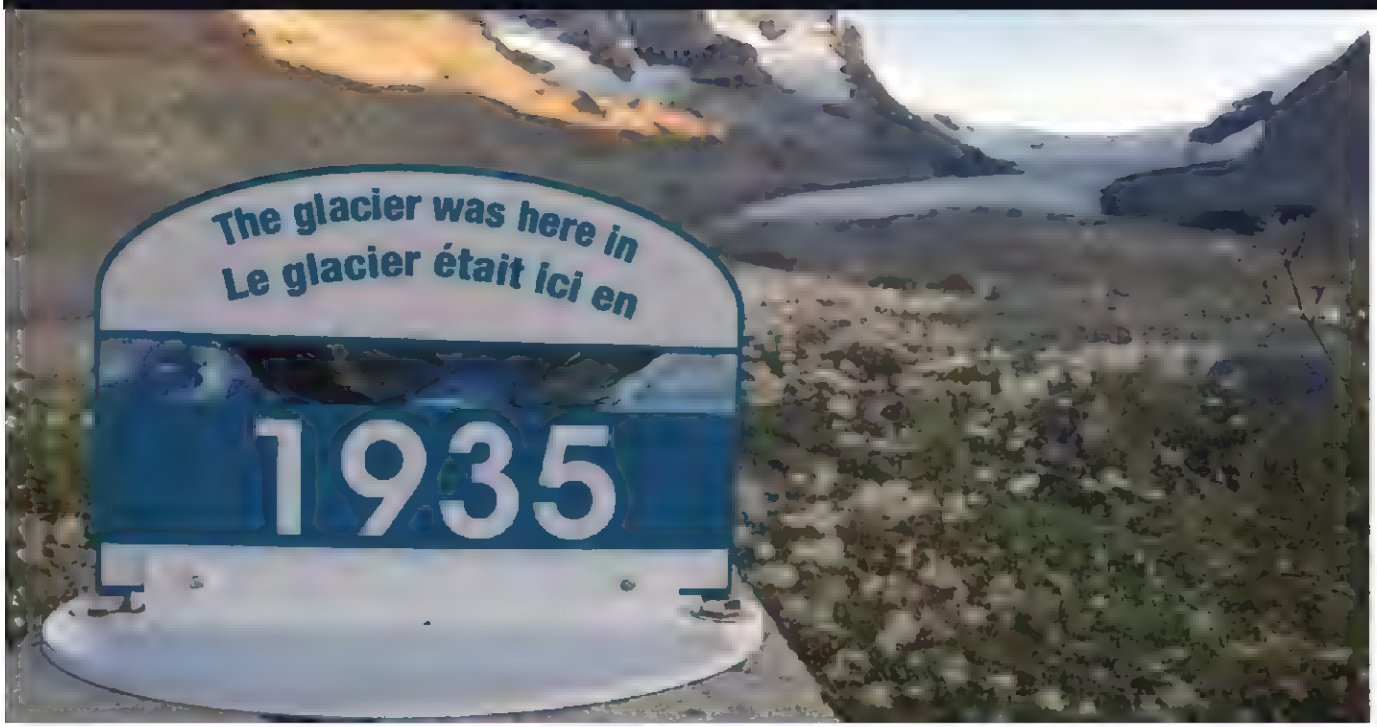
Some environmental changes are so severe or rapid that much of the plant (and animal) life may die, such as during a forest fire. Some plants, however, have adaptations that allow them to benefit from such events. For example, jack pines are often the first trees to appear after a forest fire. Jack pine seeds are sealed in the pine cone by a resin that will release the seeds only when it is heated above 50 °C. This temperature is often reached during a forest fire. Since most other living things have died and begun to decompose after a forest fire, jack pine seeds germinate in an environment with very little competition and lots of nutrients.

Plants must also respond to environmental changes caused by human activity. We might wear a path in a grassy area by walking the same way every day. We might bulldoze all the plants in an area to construct a building. Some of our actions also contribute to climate change. How plants respond to climate change can dramatically alter an environment. For example, the Athabasca Glacier in Jasper National Park has receded substantially over many decades because of global warming. As the glacier recedes, it exposes bare rock below. Land that was once under ice several metres thick is starting a gradual transformation into a forest.

STARTING POINTS

Answer the following questions using your current knowledge. You will have a chance to revisit these questions later, applying concepts and skills from the chapter.

1. Suppose that the yard of a house is left undisturbed for 20 years after the family moves away. There was grass in the yard but no trees or bushes. Predict how the yard would change over this time.
2. What factors in the environment do you think are most important to plant growth and development? Why?
3. Plants can reproduce asexually, which produces individuals that are genetically identical.
   (a) When might asexual reproduction be beneficial to a plant?
   (b) Give an example of how asexual reproduction is of economic value to people.
4. Suggest one way in which the sexual reproduction of plants is related to sustainable agricultural practices.



Mini Investigation

Which Way Is Up?

Skills: Researching, Controlling Variables, Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK A2.1

Unlike animals, plants do not have obvious sense organs. Can plants detect and respond to light, chemicals, and other stimuli in their environment? In this investigation you will examine the response of germinating seeds to the force of gravity. Later in this chapter you will learn how plants are able to respond to other environmental stimuli.

Equipment and Materials: Petri dish; filter paper; cotton batting; 4 pre-soaked seeds; tape; aluminum foil or dark paper

1. Arrange four pre-soaked seeds on the bottom of a Petri dish as shown in **Figure 1**. Each seed should be oriented toward the centre of the dish.
2. Cover the seeds with two layers of wet filter paper, being careful not to move the seeds.
3. Fill the Petri dish with enough dampened cotton batting to hold the seeds in position.
4. Place the lid on the Petri dish and tape it shut.
5. Stand the Petri dish on its edge, and tape it in position (**Figure 1**). Cover the Petri dish with foil or dark paper to keep out light.
6. Check on the seeds each day and record the growth patterns of the roots and shoots using labelled sketches.

A. Describe the overall growth patterns of your germinating seedlings. Did the roots and shoots respond to gravity in the same way? T/I

B. Why was it necessary to keep light out of the Petri dish? T/I A

C. Conduct online research to learn more about how plants detect and respond to the force of gravity. T/I A

(i) How are plants able to detect the force of gravity?

(ii) Can plants be grown in the "zero gravity" of space? If so, how?

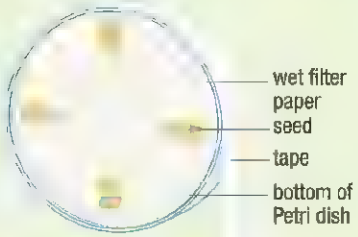


Figure 1

GO TO NELSON SCIENCE

13.1 Succession

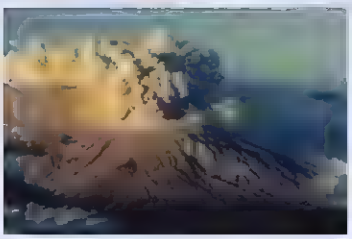


Figure 1 The ash and thermal energy released by the eruption of Mount St. Helens destroyed all life in some regions.

succession the gradual change over time in the species that form a community

primary succession succession in an area that has no plants, animals, or soil

pioneer species the first species to colonize an area during succession

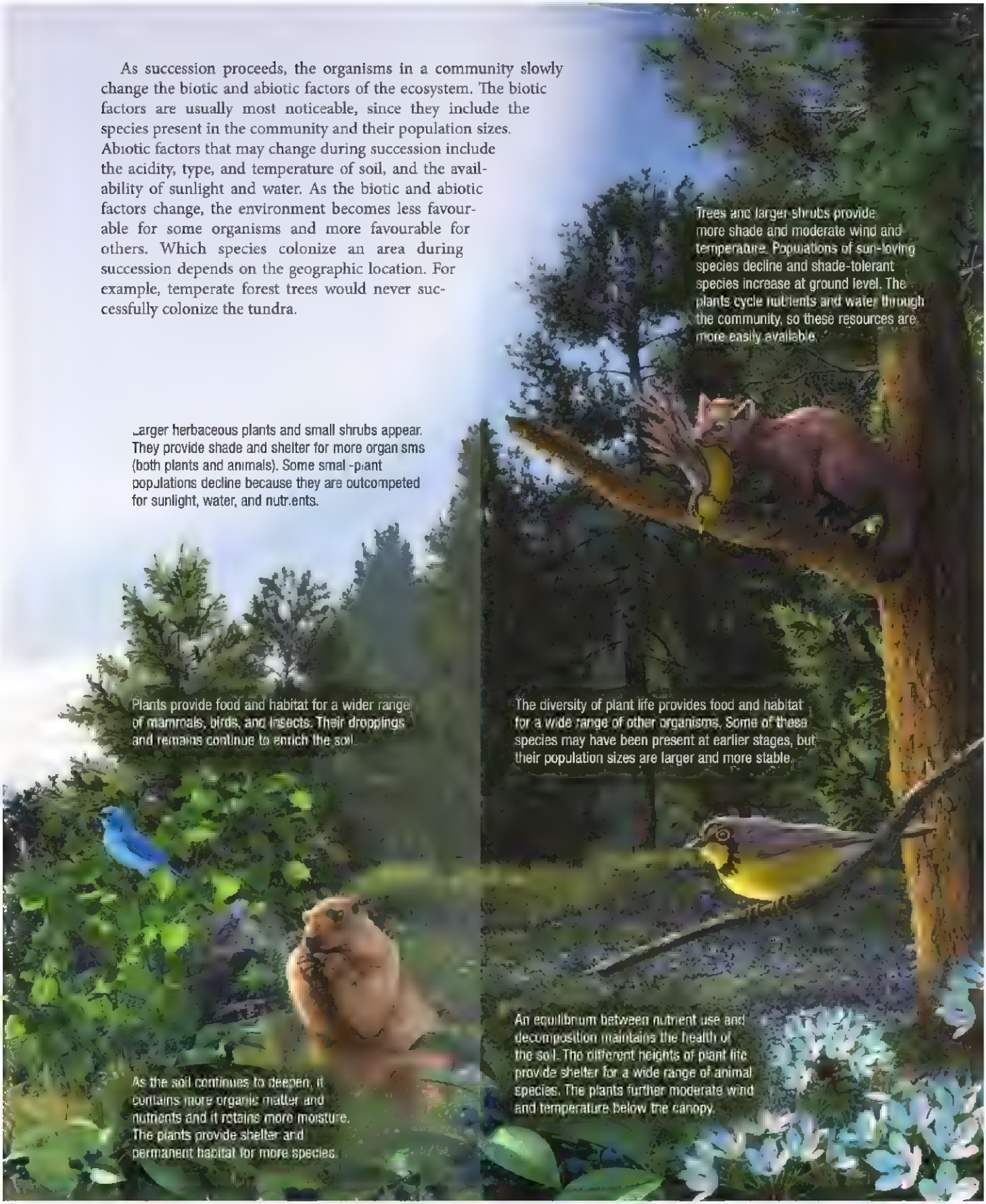
On May 18, 1980, Mount St. Helens, a volcano in the U.S. state of Washington, suddenly erupted, releasing huge plumes of volcanic ash (**Figure 1**). The thermal energy and ash from the eruption destroyed all life on the mountainside. Lava from the volcano eventually cooled to form a dome of new rock. Over the decades since the eruption, the bare rock and ash have slowly been colonized by plant and animal life. The changes in the community that are happening on Mount St. Helens are a dramatic example of succession. **Succession** is the gradual change in the species composition of a community over time. The change can be a result of shifts in the population sizes of some of the species and by the appearance and disappearance of species.

Primary Succession

Primary succession is succession that takes place on completely barren rock or mineral deposits. The thermal energy, ash, and lava of a volcanic eruption destroy all living things and cover any existing soil, creating a site for primary succession. Primary succession may also occur on lifeless surfaces exposed by retreating glaciers and explosions. Primary succession begins when organisms first colonize the bare surface. These first colonizers are called **pioneer species**. **Figure 2** shows the overall steps in primary succession that could occur at the edge of a receding glacier. Notice how, as succession proceeds, the biodiversity of the community increases.

Figure 2 Primary succession at a glacier's edge begins with bare rock, which is slowly colonized by an increasing number of species. The final result is a diverse community of organisms. Primary succession after a glacier retreats takes roughly 200 years.

As succession proceeds, the organisms in a community slowly change the biotic and abiotic factors of the ecosystem. The biotic factors are usually most noticeable, since they include the species present in the community and their population sizes. Abiotic factors that may change during succession include the acidity, type, and temperature of soil, and the availability of sunlight and water. As the biotic and abiotic factors change, the environment becomes less favourable for some organisms and more favourable for others. Which species colonize an area during succession depends on the geographic location. For example, temperate forest trees would never successfully colonize the tundra.



secondary succession succession in an ecosystem that has been disturbed by a natura event or human activity

Eventually, the shifts in plant populations slow down and a stable community is formed. Although it is stable, the community still responds to environmental changes. For example, an increase in the average temperature (such as from global warming) might make a region warmer and dryer, which would cause an increase in the number of drought-resistant species. We still have a lot to learn about primary succession, and several studies are ongoing around the world.

CAREER **LINK**

Freshwater Biologist

Freshwater biologists may monitor the changes in freshwater communities or be involved in re-establishing damaged ones, such as lakes in which all life was killed by acid rain. To learn more about a career as a freshwater biologist,

GO TO NELSON SCIENCE

Secondary Succession

Secondary succession is succession that occurs after an existing community has been disturbed by natural events or by human activity. Natural events include forest fires, floods, and violent storms such as tornadoes and hurricanes. Human activities include forest harvesting as well as clearing land for agriculture or for construction. Unlike primary succession, secondary succession takes place where soil containing organic matter and sometimes a few plants may remain after the disturbance. The plant populations in the community therefore establish more quickly than in primary succession. **Figure 3** shows how succession might occur on farmland that was abandoned and left undisturbed. Although our example is of a terrestrial community, secondary succession also occurs in aquatic environments.

Figure 3 As with primary succession, biodiversity increases as secondary succession progresses

Human Activity and Succession

Figure 4 In this schoolyard, plants that would have arisen by success on in a natural environment have been planted in a previously grassed area

Succession creates stable, diverse communities. The more diverse a community is, the better it can withstand environmental change. Unfortunately, many human activities get in the way of succession. For example, traditional suburban yards are dominated by a monoculture of grass. Some people ensure that succession does not proceed by actively destroying any non grass species that colonize their lawns, either by weeding or by using herbicides. Such actions can reduce plant and animal biodiversity. However, people are modifying their actions in ways that allow us to meet our needs and wants while minimizing negative effects on succession and biodiversity. For example, some gardeners allow native plants to colonize their gardens. When forestry companies switch from clear-cutting to selectively cutting trees of a particular size, the plant community remains at a later stage of succession and is more stable.

Human actions can also help to advance the stages of succession, increasing biodiversity and stability in communities. For example, some schoolyards and parks are planted with species that would eventually arise naturally by succession (**Figure 4**). It is important to plant species that are only one or two stages ahead in succession. This helps ensure that the plants are in a community with biotic and abiotic factors that can support their growth and development.

Research This

The Greening of Sudbury

Skills: Researching, Analyzing, Communicating, Identifying Alternatives

SKILLS HANDBOOK A5.1

Sudbury is a greening city. As you can see in **Figure 5(a)**, the environment in and around the city was once severely degraded by industries operating in the area. Emissions from nickel smelting caused acid rain, which acidified the soil in and around Sudbury until virtually all plant life was killed off.

Although the environment has not yet completely recovered from the negative effects of industry, it has slowly undergone succession and recovery (**Figure 5(b)**). However, this succession has been possible only because of the intervention of environmental groups. In the case of Sudbury, it was not sufficient to simply plant species that would occur eventually by succession. The environmental conditions in damaged areas had to be changed before any plant species could survive. In fact, some areas near Sudbury remain barren of life.

Figure 5 (a) Degraded land near Sudbury, 1977 (b) Reclaimed land near Sudbury

1. Use the Internet and other sources to find out more about the work involved in greening Sudbury. Find out what was done to begin the process of succession and what is continuing to help it occur more quickly.

A. Create a flow chart, timeline, or other graphic organizer to show how people in Sudbury worked with succession to help rehabilitate damaged environments. T/I C

B. Some areas have yet to be rehabilitated. Why? T/I

C. Using what you know about succession and biodiversity, suggest further steps that groups and governments in the Sudbury area could take. T/I A

GO TO NELSON SCIENCE

13.1 Summary

- Succession is the gradual change in a community brought about by shifts in population sizes of various species and/or loss or gain of particular species.
- Primary succession occurs in an area in which there is no existing life.
- Secondary succession occurs after a community has been disturbed; soil with organic nutrients and some plant species remain after the disturbance.
- At each successional stage, biotic and abiotic conditions change; each species may be more or less successful in the new conditions. Eventually, succession results in a stable community with relatively small changes in populations.
- Biodiversity increases at every stage of succession.
- Human action can affect the process of succession positively or negatively.

13.1 Questions

1. Explain how succession and biodiversity are related. K/U T/I
2. Distinguish between primary succession and secondary succession. K/U
3. Give an example of how human activity can cause primary succession and secondary succession. Which type of succession is more often affected by human actions? K/U
4. Does a stable community remain the same? Explain. K/U
5. Suppose there is a weedy section of grass in your schoolyard. Using what you know about succession, how could you improve the biodiversity of this area? T/I A
6. Some plants produce large numbers of very small seeds while others produce a few large seeds. Predict which type of plants are more likely to be found in early successional stages. Explain your reasoning. T/I A

13.2 Asexual Reproduction in Seed Plants

Figure 1 Many of these grass plants growing in the dunes of Pinery Provincial Park are produced by asexual reproduction

If you have ever walked along a beach, you may have noticed large clumps of grass growing in the sand. Grasses are often pioneer species on newly formed sand dunes. Once a single grass seed germinates and grows in the sand, it can quickly give rise to a large population (**Figure 1**). The swift increase in individual grass plants is accomplished by asexual reproduction, in which a single parent produces offspring by cell division. In plants, asexual reproduction is also called vegetative reproduction. Grass species can reproduce asexually by producing rhizomes, underground stems from which new plants arise (**Figure 2**).

Figure 2 A grass plant dug up to show a rhizome.

Structures Involved in Asexual Reproduction

Plants use a number of structures to reproduce asexually. Some, like rhizomes, are modified stems. These include corms, stolons, and the "eyes" on tubers (**Figure 3(a)**). Other plant structures are modified leaves, such as in the kalanchoe plant (**Figure 3(b)**). Suckers are new shoots that grow from a plant's roots and can form new plants (**Figure 3(c)**).

Sometimes new plants can grow from fragments of roots or shoots. For example, if a gardener breaks off a small portion of a dandelion's taproot when pulling out the plant, a new dandelion will grow from the fragment left in the soil.

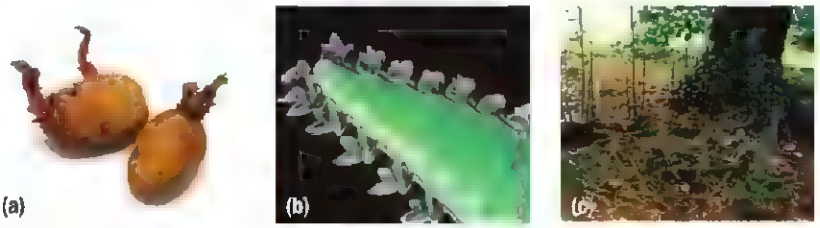


Figure 3 New plants can arise from (a) tubers, (b) leaves, and (c) roots.

LEARNING TIP

Modified Plant Structures
The anatomy of the modified structures that are involved in asexual reproduction was discussed in Chapter 12.

Investigation 13.2.1

Methods of Asexual Reproduction (page 619)
After reading about plant structures involved in asexual reproduction, you can complete Investigation 13.2.1.

In this observational study you will take cuttings from two different plant species and observe the effects of light exposure and lack of light on root formation in each species.

Costs and Benefits of Asexual Reproduction

Asexual reproduction in plants usually occurs by mitosis of diploid cells. As a result, asexual reproduction produces genetically identical individuals (clones). Why do plants reproduce asexually? Asexual reproduction has several benefits:

- If a plant has traits that allow it to survive in a particular environment, all of its offspring will have these traits, and they can all take advantage of the resources in the environment.
- The plant does not have to produce specialized reproductive structures, such as flowers or cones, so reproduction takes less energy and produces new individuals more quickly.
- Only one plant is needed. The plant does not depend on the presence of another individual in order to reproduce.
- Plantlets formed by asexual reproduction are generally more robust than young seedlings produced by sexual reproduction, so plantlets have a higher survival rate.

There is one big cost to reproducing asexually. As you learned from the Evolution unit (Unit 3), the environment selects only those individuals with traits that allow them to survive and reproduce in that environment. A population created by asexual reproduction is genetically identical. This lack of variation can have serious consequences. If the environment changes significantly, all of the individuals could die if their traits no longer help them survive and reproduce. For example, if the dune grass population were susceptible to a deadly plant virus, the virus could wipe out the whole population. To get around this problem, species reproduce sexually as well. For example, the grass plants produced by asexual reproduction will eventually reproduce sexually by producing flowers and forming seeds.

LEARNING TIP

Mitosis
Mitosis is the division of cells after duplication of their DNA. The daughter cells of mitosis have identical genetic material.

Human Uses of Asexual Plant Reproduction

Early in human history, people recognized that they could take advantage of plants' ability to reproduce asexually. They realized that they could use the various plant structures to grow more plants. Early farmers also found that they could use asexual reproduction to produce copies of those plants that had desirable characteristics.

Today, gardeners, farmers, and commercial nurseries still use asexual reproduction to clone desirable plants. One of the simplest methods is to take a stem cutting and place it in water. Some species quickly grow new roots at the cut edge (**Figure 4(a)**). Once roots form, the cutting can be transferred to soil (**Figure 4(b)**).

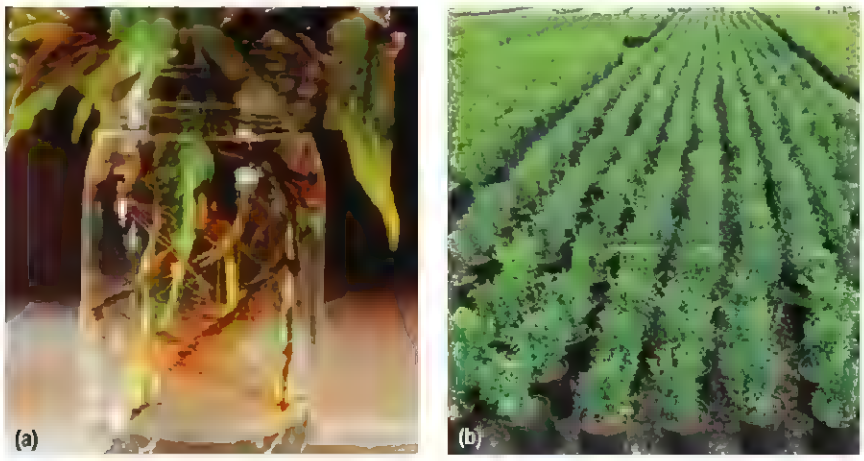


Figure 4 (a) Roots form on a cutting. (b) Commercial nurseries produce genetically identical plants grown from cuttings.

grafting attaching a young branch from one plant to the stem and root of another plant

scion the detached young branch from a plant

stock the plant onto which a scion is grafted

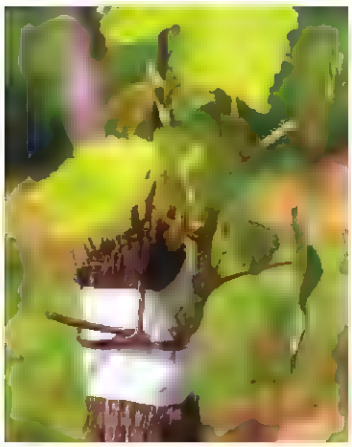


Figure 5 Scions of grape plants that produce desirable fruit are often grafted onto the stock of individuals with hardy disease- and insect-resistant roots.

Some growers use specific techniques to induce asexual reproduction in ways that do not occur naturally. One common example is grafting. **Grafting** involves cutting a young branch from a plant that has desirable characteristics and attaching it to the stem of another plant. Usually both plants are of the same or closely related species. The branch is called the **scion** and the plant that provides the stem and root system is called the **stock** (**Figure 5**). In a successful graft, the cambium of the scion and the cambium of the stock grow together, so that the vascular tissue of the stock eventually fuses with the vascular tissue of the scion. Plants in orchards and vineyards are maintained primarily by grafting. Often scions from a single tree that produced desirable fruit are grafted onto all the plants in the orchard or vineyard. For example, if an orchard has trees that produce McIntosh apples, all the branches that produce the apples are grafts of scions from a single apple tree. Grafting allows growers to produce multiple copies of a desirable tree or vine, but it does have a disadvantage. If most scions are from only a few individuals, the genetic diversity of the orchard or vineyard can be very low. This can make the plants vulnerable to disease, pests, or changes in environmental conditions.

Some plants cannot reproduce asexually. Others reproduce asexually only with difficulty. To overcome this, scientists have developed ways of producing clones by culturing particular tissues (**Figure 6**). Scientists grow these clones by placing a piece of a plant into a series of culture media where the plant tissue can grow into a complete plant. You will learn more about tissue culture in Section 13.6.

Figure 6 Apricot plants being grown in culture media in test tubes

13.2 Summary

- Asexual reproduction, also known as vegetative reproduction, produces genetically identical copies (clones) of an individual plant.
- Structures used in asexual reproduction include bulbs, rhizomes, and scions.
- Benefits of asexual reproduction include the ability to reproduce rapidly.
- Asexual reproduction techniques are used in agriculture to produce copies of plants with desirable traits.

13.2 Questions

1. Give two examples of plants that can reproduce asexually and the structures that they use. K/U
2. How might the ability to reproduce asexually be of particular benefit to pioneer plant species? K/U A
3. How does the use of asexual reproduction help fruit growers produce a consistently high-quality harvest? K/U MC
4. List the advantages of asexual reproduction. K/U
5. Would you expect a changing environment to benefit plants that reproduce asexually or sexually? Explain your reasoning. K/U C/S
6. Describe the process of grafting. K/U
7. You hear a scientist comment to an orchard grower, "By producing all your new trees by grafting, you will never be able to improve the flavour of your fruit." Explain the scientist's reasoning. Do you think this is a significant concern? K/U T/I A

13.3

Sexual Reproduction in Seed Plants

In the previous section you saw that plants can reproduce by asexual reproduction, which can quickly establish a population of plants. However, asexual reproduction cannot begin until at least one individual grows in an area. How does a plant get to a new area? In most vascular plants, it is by their seeds. The seed is the critical structure that allows the introduction of an individual to a new area (**Figure 1**).

Figure 1 After a fire, the seeds of the jack pine are released from the cones into the community. These along with seeds carried in from elsewhere, start the process of secondary succession

CAREER LINK

Forest Fire Management

Some forest fires are a natural part of the developmental cycle of a forest. Species such as the jack pine could not survive without forest fires. However, other fires are caused by human activity and are more destructive than helpful. Forest fire management can involve determining when to let a fire burn and when to douse it. To learn more about a career in forest fire management,

GO TO NELSON SCIENCE

Seed Function and Structure

A seed has two main functions: to protect and nourish the enclosed embryo, and to carry the embryo to a new location. Seeds, and in the case of angiosperms, the fruits that contain them, have a wide range of structures and mechanisms to help them disperse (**Figure 2**). The ability of plant seeds to travel to a new location is crucial to introducing a species to a new area during succession. It is also important once a plant has established itself. Dispersal can move a plant's seeds to a location where there is less competition from other plants for resources, which increases the seeds' chances of survival.

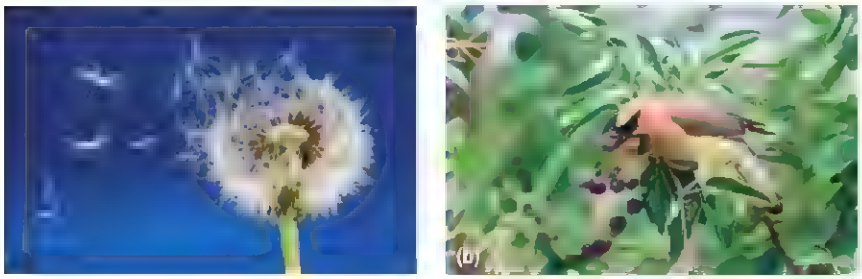


Figure 2 Seeds are dispersed primarily by wind and animals. (a) Dandelion seeds have special structures that allow them to be carried long distances by wind. (b) The nutrient-rich tissues of some seed-containing fruits, such as serviceberries, attract mammals and birds, which carry them away from the parent plant. If the seeds then fall on fertile ground, they can grow.

endosperm the nutritive tissue in an angiosperm seed

Figure 3 shows examples of the general structures in monocot and eudicot seeds. The seeds of these plant groups contain an embryo, nutritive tissue to support embryo growth, and a protective seed coat. In angiosperms, the nutritive tissue may be supplied either by cotyledons or by a specialized nutritive layer called the **endosperm**. The seeds of angiosperms are contained in fruits, but gymnosperm seeds are not.

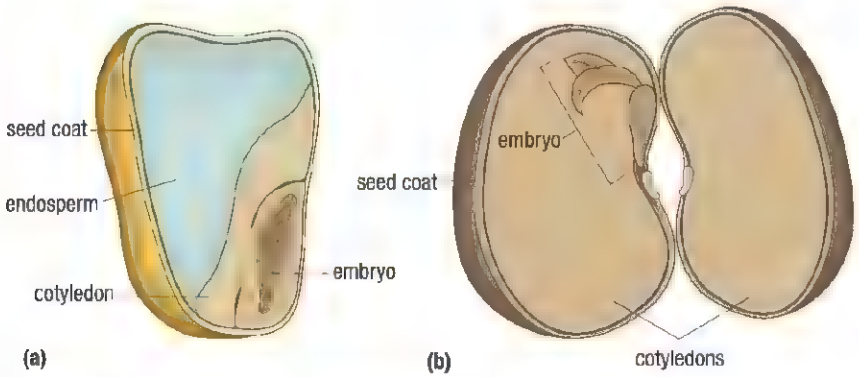


Figure 3 General seed structure in angiosperms (a) A monocot and (b) a eudicot

LEARNING TIP

Chromosome Number
During meiosis, the number of chromosomes in a cell is halved, usually from diploid ($2n$) to haploid (n). Chromosomes undergo independent assortment during meiosis. You can review meiosis in Chapter 4.

Costs and Benefits of Sexual Reproduction

Unlike asexual reproduction, sexual reproduction involves the union of two haploid cells. Sexual reproduction requires structures and cells that are devoted entirely to this process. A plant must devote a lot of resources to sexual reproduction, so when resources are scarce, carrying out sexual reproduction can lower the chances that an individual organism will survive. However, the potential costs of sexual reproduction are outweighed by its advantages.

- Populations produced by sexual reproduction have a high level of genetic diversity. If the environmental conditions change, there is a higher chance that some individuals in a genetically diverse population will have traits that are suited to that environment and will survive and reproduce.
- The products of sexual reproduction are seeds. Seeds can be dispersed away from the parent plant, and so the seedlings may have less competition for resources or better growing conditions.
- Seeds can remain dormant for long periods and then germinate when conditions are favourable, increasing the chance of survival.

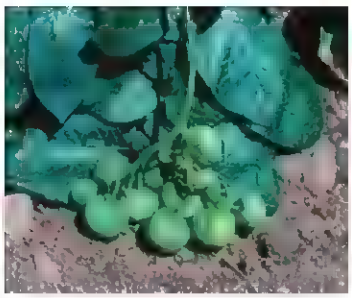


Figure 4 Fruits of a potato plant

Many plants can readily reproduce both sexually and asexually. For example, a potato plant produces numerous tubers from which genetically identical plants can arise. It also produces seeds by sexual reproduction. These are found in fruits that resemble small green tomatoes (**Figure 4**).

When a plant reproduces sexually, it uses specific structures and processes. These structures and processes vary among the different plant groups.

Sexual Reproduction in Gymnosperms

Cone-bearing gymnosperms, such as pines and cedars, provide us with most of the wood used in construction and paper products, as well as other useful products such as disinfectants and varnishes. The reproduction of gymnosperms therefore has great importance to our way of life. Conifers produce both male cones and female cones. Haploid cells called microspores are produced by meiosis within male cones. Each microspore develops into a pollen grain containing a male gametophyte. Meiosis in female cones produces megaspores that give rise to the egg-producing female gametophyes.

Pollination and Fertilization

Pollen grains have to get from a male cone to an ovule in a female cone. This happens by pollination. **Pollination** is the process of transferring pollen grains to an ovule. All gymnosperm pollination takes place by wind. The surface and structure of pollen grains help them to be carried by wind (**Figure 5**). In gymnosperms, pollination happens only when a pollen grain lands close to an ovule on a female cone (most pollen grains do not). A sticky resin and the cone's scale shape then help guide the pollen to the ovule. The pollen grain grows a **pollen tube**, which is a tube that grows down to the ovule.

As the pollen tube grows, its haploid nucleus divides by mitosis, producing two haploid sperm nuclei. Once the pollen tube reaches the female gametophyte, it releases the two sperm nuclei. One sperm nucleus fertilizes the egg, and the diploid zygote is formed. The other sperm nucleus degrades. It takes about 13 months for the egg to be fertilized after the pollen grain lands on the ovule. Upon fertilization, the ovule develops the various structures in the seed, and the zygote develops into the embryo. If this seed germinates, it may eventually become a mature sporophyte, and the cycle will be repeated (**Figure 6**).

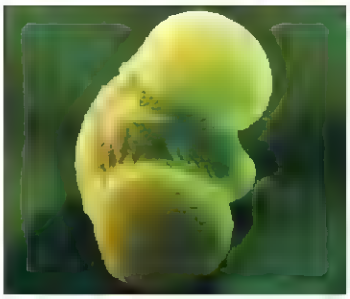


Figure 5 Pollen grain from a Scots pine (×1600 magnification)

pollination the transfer of pollen grains to an ovule

pollen tube a hollow tube that grows out of a pollen grain and carries the pollen nucleus to the female sex cell

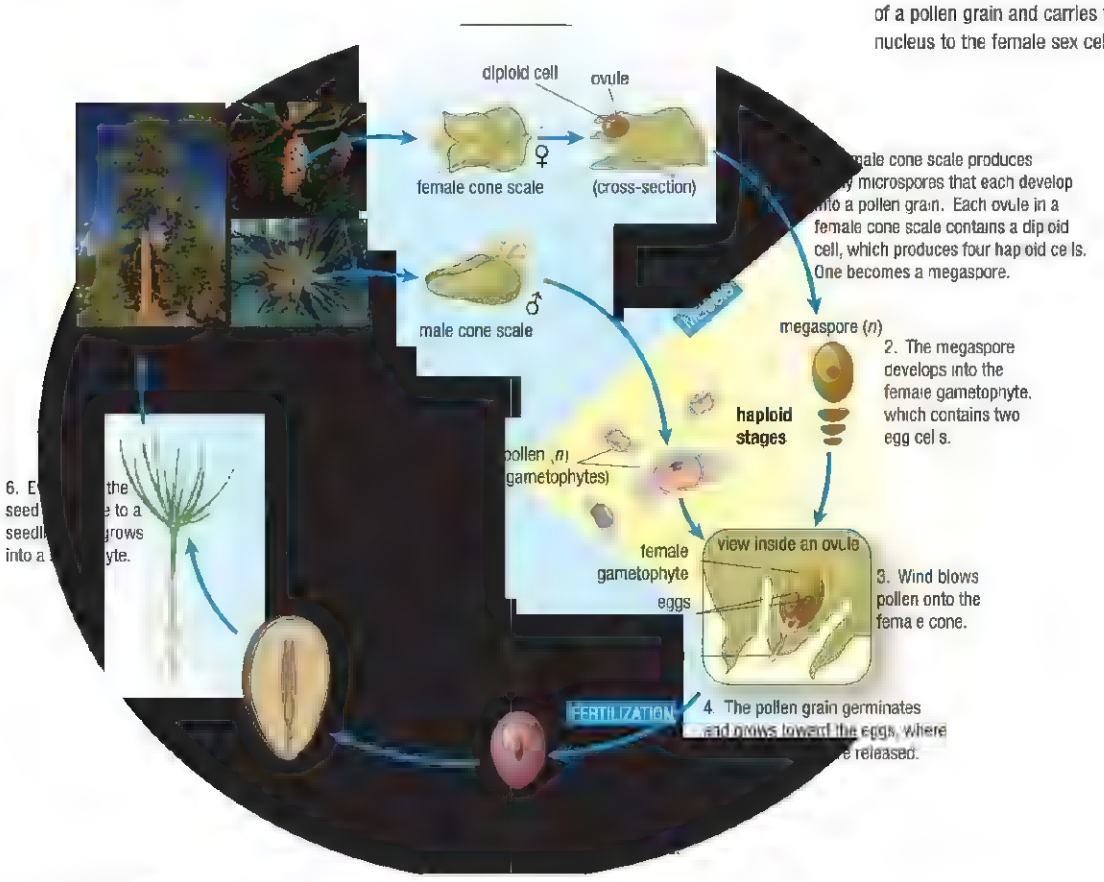


Figure 6 Life cycle of a gymnosperm

Sexual Reproduction in Angiosperms

The products of sexual reproduction in angiosperms are seeds contained inside a fruit, which is a mature or ripened ovary. These seeds and fruit are important to many organisms, since they contain energy and nutrients. For example, squirrels and many birds depend on angiosperm seeds to get through the winter months. Much of the human diet comes from angiosperm seeds and fruits.

stamen the male reproductive floral part comprising an anther and a filament

anther the floral organ that produces pollen

filament the thin stalk that supports the anther

carpel the female reproductive floral part, comprising a stigma, a style, an ovary, and an ovule

stigma the sticky surface on top of the style

style the stalk that leads to the ovary

Flowers are the key organs in sexual reproduction of angiosperms. **Figure 7** shows the generalized structure of a flower. The **stamens** make up the male reproductive flower parts. A stamen is composed of an anther and a filament. The **anther** produces pollen grains. The **filament** raises the anther above the female organs. The **carpel** includes the female reproductive parts. The **stigma** is a sticky surface that acts as a landing site for pollen grains. Below the stigma is the **style**, a tube-like structure that leads down to the ovary. The ovary contains one or more ovules, each of which forms a seed when it is fertilized.

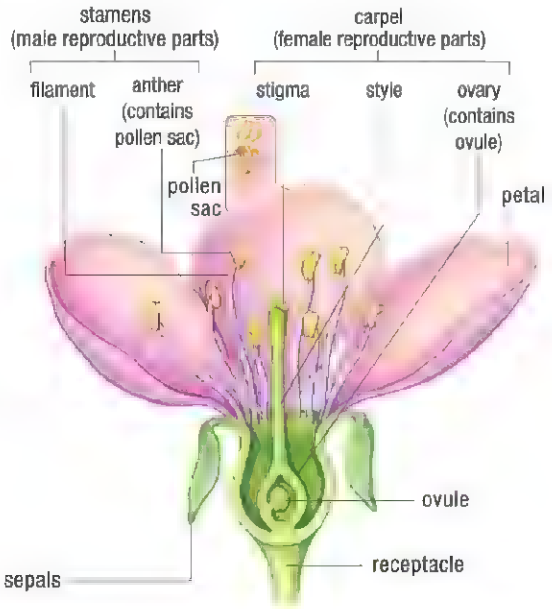


Figure 7 The flower of the wild rose contains both male and female structures

There are distinct differences between monocot and eudicot flowers (**Figure 8**). The petals and stamens of monocot flowers are always in multiples of three. In eudicot flowers, petals and stamens are in multiples of four or five.

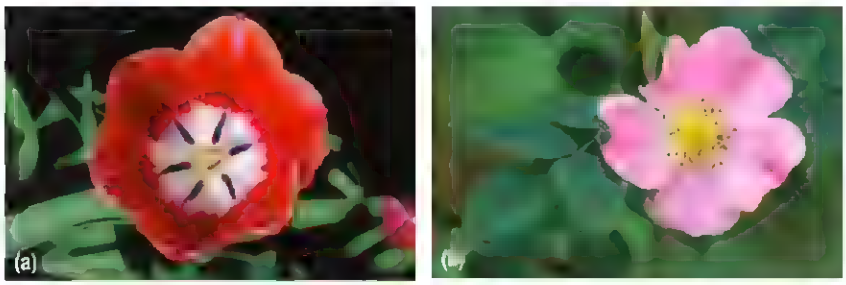


Figure 8 (a) The floral parts of monocots, such as this tulip, are always in groups of three or in multiples of three. (b) The floral parts of eudicots, such as this rose, are always in groups of four or five, or multiples of these.

Figure 9 The flower of the dragon arum plant is very large and smells like rotting flesh to attract flies.

Many animal-pollinated flowers are very showy, such as the dramatic flower shown in **Figure 9**, while wind-pollinated flowers, such as the flowers of a maple tree or a wheat plant, often go unnoticed. Not all species have all the structures shown in Figure 7. In some species, such as corn, each plant produces two types of flowers: the "tassels" on the top of the plant are flowers that have only male structures, and the cobs that grow lower on the plant are flowers that have only female structures. In other species, such as willows, an individual plant produces only male flowers or only female flowers. Some species, such as pepper plants, have many ovaries fused together, which contain many ovules.

Figure 10 (next page) shows the changes that take place in flower structures during the life cycle of a typical angiosperm.

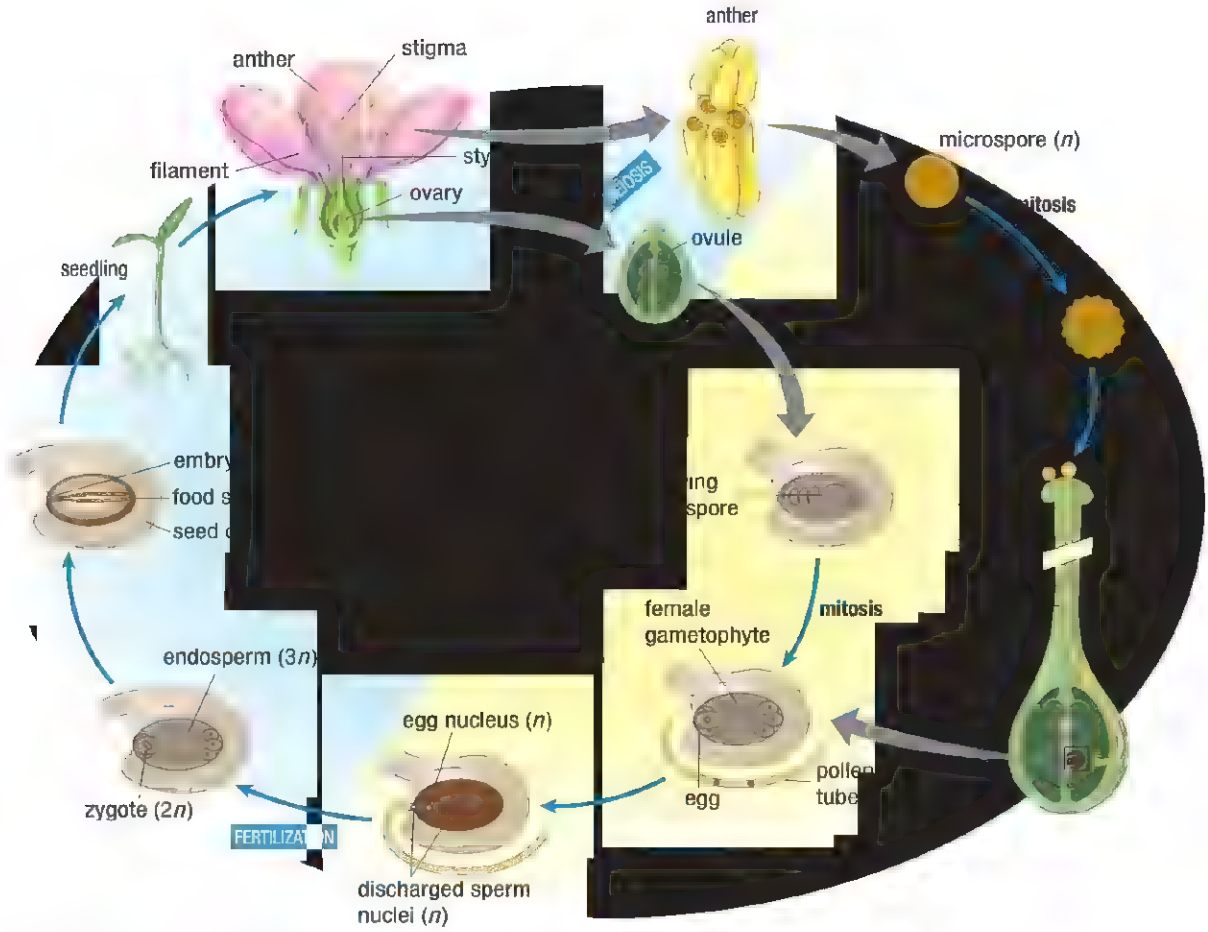


Figure 10 Life cycle of an angiosperm

Pollination and Fertilization

In angiosperms, pollination happens by wind or by animals, depending on the species. Animals that transfer pollen from one plant to another are called pollinators. Most pollinators are insects, such as bees, but other species can also be pollinators (**Figure 11**).

Figure 11 (a) Butterflies, (b) hummingbirds, (c) some bat species, and (d) flies all transfer pollen as they feed on nectar and pollen produced by flowers.

cross-pollination the transfer of pollen grains from one plant to another

self-pollination the transfer of pollen from one flower to another on the same plant

Unlike in gymnosperms, angiosperm pollination varies. Most species can only cross-pollinate. In **cross-pollination**, pollen grains must be transferred from one individual plant to another. Some plants, such as wheat and peas, can self-pollinate. In **self-pollination**, pollen can be transferred from one flower to another on the same individual plant. Plants that are capable of self-pollination can also cross-pollinate.

In angiosperms, an anther releases many pollen grains, which are then carried by wind or by a pollinator to the stigma of another flower. Pollination occurs as soon as a pollen grain sticks to the stigma. When conditions are right, the pollen grain begins to grow a pollen tube. The pollen tube grows down the style until it reaches the ovary. As with gymnosperms, the pollen tube of angiosperms carries two haploid sperm nuclei to the ovary.

Once the pollen tube reaches the ovary, both sperm nuclei are involved in separate fertilization events. This is called double fertilization. One sperm nucleus unites with the egg cell contained in the ovary, forming the diploid zygote. The second sperm nucleus fuses with two polar nuclei in the ovule, forming a triploid ($3n$) cell. This triploid cell develops into the endosperm.

fruit mature ovary of an angiosperm, which contains the seed(s)

pericarp the fruit wall, which develops from the ovary wall of a fertilized angiosperm carpel

CAREER **LINK**

Fruit Grower

To find out more about careers related to fruit production,

GO TO NELSON SCIENCE

Fruit Formation

A **fruit** is a mature ovary. Fruit development starts when an ovule is fertilized during double fertilization. The ovary wall develops into the fruit wall, called the **pericarp**. The pericarp may be fleshy or dry. A fruit helps to protect and disperse the seed, but the fruit does not provide nutrients to the developing embryo. Commonly, the word "fruit" is used for sweet, fleshy fruits, such as plums or strawberries, while "nut" and "grain" are used for dry fruits, such as walnuts or wheat. Fruits that are less sweet, such as peppers, squash, tomatoes, and peas, are usually called "vegetables" in everyday speech. However, the correct scientific term for any structure that is formed from a ripened ovary is "fruit" (**Figure 12**).

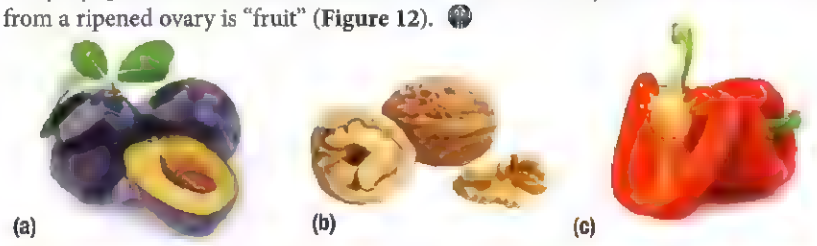


Figure 12 (a) Plums, (b) walnuts, and (c) red peppers are all fruits.

Research This

Disappearing Pollinators

Skills: Researching, Analyzing, Evaluating, Communicating, Defining the Issue, Identifying Alternatives, Defending a Decision SKILLS HANDBOOK A5.1

Angiosperms make up almost all food crops worldwide. Most of this food consists of seeds and fruits, which depend on pollination. Some scientists estimate that one mouthful in three requires insect pollination. Much of the variety in the flower structure of plants is designed to attract and stick pollen to a pollinator. In return, the plant gives food in the form of nectar and pollen to its pollinators. The most important insect pollinator in Canada is the European honeybee. Europeans brought this bee species to North American around 1638.

Unfortunately, recent studies have shown that the number of pollinators worldwide is falling. Honeybee populations have received the most attention. A condition called colony collapse disorder has decimated commercial hives, which in turn has reduced the productivity of fruit and vegetable crops that depend on these bees

In 2009, the annual value of crop pollination by commercial honeybee hives in Canada was about $1.2 billion.

Conduct research to find out more about the importance of pollinators to food production and the factors that are causing a decline in their numbers.

1. What do scientists think are the leading causes of colony collapse disorder?
2. What are Africanized bees, and how do they affect pollination of crops?
3. What other factors are affecting bee popu ations?

A. Canada has a number of native bee species. Given this, do you think that the decline in honeybee popu.ation is a serious problem? Explain. T/I A

B. Suggest changes that Canadians could make in their activities to help maintain the population of pollinators. T/I A

GO TO NELSON SCIENCE

Human Uses of Seeds and Fruits

Seeds of angiosperms such as wheat, rice, and corn serve as food staples for most humans. Seeds also have had a profound influence on the development of human culture. For example, the Hopi and other indigenous peoples of Central and North America refer to themselves as "The People of the Corn."

The development of agriculture depended on people learning to collect and save seeds. Much plant breeding still involves collecting seeds from plants with desirable traits. In developing countries, agriculture depends on individual farmers saving seeds from each year's crop. In countries such as Canada, agricultural companies rather than individual farmers carry out most seed production.

Seed (grain) and fruit production is an important industry worldwide. In 2009, Canadian grain crops were worth $13 billion, and fruit and vegetable crops were worth $753 million. Most growers plant monocultures (for example, an apple orchard or a wheat field). This method is efficient, but it greatly reduces biodiversity and often relies on the use of fertilizers, pesticides, and irrigation (a watering system), as well as machinery that uses fossil fuels. Some fruits, such as peppers and tomatoes, are grown in greenhouses, which may require even more intense use of non-renewable resources.

Farmers, growers, scientists, and home gardeners are making changes to make fruit production more sustainable. These changes include growing varieties bred to be more resistant to pests, disease, or drought; covering soil to reduce moisture loss; and planting more than one species in an area (**Figure 13(a)**). Some greenhouse operators use predatory insects to limit pest infestations rather than using chemical insecticides. We can all make fruit production more sustainable by buying locally grown fruit in season and growing our own fruits in our yards or in community gardens (**Figure 13(b)**).

WEB LINK

Corn and Culture
To learn more about how corn cultivation affected the growth of civilization in the Americas,

GO TO NELSON SCIENCE

CAREER LINK

Seed Supplier
To find out more about careers related to seed production,

GO TO NELSON SCIENCE

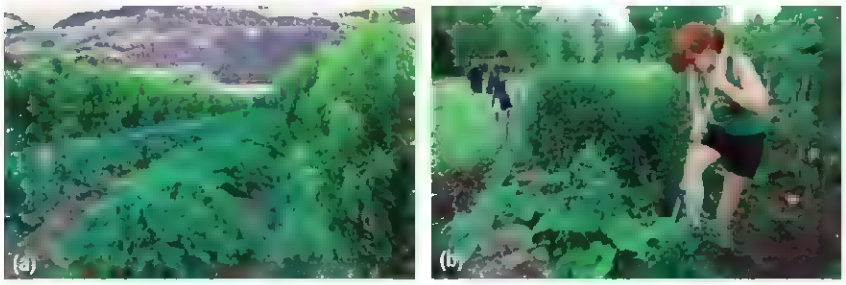


Figure 13 (a) Squash and zucchini planted between nectarine trees. (b) Community gardens in cities are becoming increasingly popular.

Research This

Seed Banks

Skills: Researching, Analyzing, Communicating, Defining the Issue, Defending a Decision

SKILLS HANDBOOK A5.1

Approximately 75 % of the genetic diversity of agricultural crops has been lost in the last century. Over time, we have also come to rely on only a few plant species for food. Scientists estimate that 90 % of all human food energy comes from only 15 crops. The big three—rice, maize (corn), and wheat—provide 60 % of our food energy needs! Given the significance of a relatively small number of crops, it is vitally important to conserve the diversity within these major crops for global food security.

1. To keep our food supply secure, several nations have developed seed banks. Use the Internet to research seed banks and then answer the following questions.

A. (i) What is a seed bank? Give an example of a specific seed bank in your answer.

(ii) Do seed banks store only crop plants? Why or why not?

(iii) Storing seeds in seed banks is costly because the environment must be strictly controlled. Do you think this cost is justified? Explain.

B. Conduct research to find out about seed banks around the world.

C. Determine what criteria seed banks use to choose which seeds to store, and why.

D. Identify the main reason why seed banks are being expanded.

GO TO NELSON SCIENCE

13.3 Summary

- Seeds are the product of sexual reproduction; they, along with fruits, provide a dispersal mechanism and protect the embryo within them.
- Seeds are produced when haploid male sex cells in pollen unite with haploid female sex cells in an ovule.
- In gymnosperms, the pollen is produced in smaller male cones, and pollination and fertilization occur in the ovules contained in larger female cones.
- In angiosperms, the main reproductive structure is the flower. Pollen is produced by anthers on the stamen. The carpel contains the stigma and the style, which leads down to the ovary. The ovary contains one or more ovules, which form seeds after pollination and double fertilization.
- Angiosperm seeds are produced within a fruit, which is a ripened ovary.
- Seeds are an important food source for many organisms, including humans.
- Human culture was advanced by understanding and using seeds.
- Traditional methods of producing angiosperm fruit by monoculture are not sustainable. However, methods that are more sustainable continue to be developed.

13.3 Questions

1. What are the main functions of a seed? Given these functions, why is it not surprising that seeds are an excellence source of nutrients? K/U A
2. Seeds do not germinate until conditions are right. How does this compare with the hatching of a bird's egg? What advantage does this adaptation give plants? K/U A
3. Make labelled diagrams of a monocot and eudicot. In what ways are the seeds similar? How do they differ? K/U C
4. List and state the functions of each of the seed parts you labelled in Question 3. K/U
5. Describe the unusual adaptation of jack pines for releasing their seeds. Relate this feature to the ecological process of succession. K/U A
6. Describe the function of pollen in gymnosperm and angiosperm sexual reproduction. K/U
7. Some pollen grains are dry and some are sticky. T/I C
   (a) Which would you expect to be carried on wind and which on the body of a pollinator?
   (b) Many people have pollen allergies. Suggest whether dry or sticky pollen would cause more allergies. Give reasons for your answer.
8. In angiosperms, pollination occurs when the pollen lands on and sticks to the stigma. Has fertilization occurred at this point? If not, describe the events that lead to fertilization. K/U
9. Define the scientific term "fruit" and give four examples of fruits. Include examples that are commonly referred to as grains, nuts, and vegetables. K/U T/I C
10. Is the traditional way of growing fruit sustainable? Explain why or why not. T/I A
11. Name at least three things you could do to reduce the negative effects of fruit production on the environment. Would you be willing to do these things? Why or why not? K/U A
12. Create a table or a graphic organizer that summarizes all the structural differences between monocot and eudicot angiosperms that you have encountered so far in this unit. K/U C

13.4 Explore an Issue in Energy Alternatives

Biofuels

SKILLS MENU

- Defining the Issue
- Researching
- Identifying Alternatives
- Analyzing
- Defending a Decision
- Communicating
- Evaluating

On April 22, 2010, a deep-water oil rig exploded and leaked millions of litres of crude oil into the Gulf of Mexico. Images of the resulting environmental catastrophe, such as oiled birds and turtles, saddened and angered people worldwide. It also motivated a push for faster development of alternative energy sources.

One possible alternative to fossil fuels is biofuel. Biofuel is an energy source produced from plant matter. Biofuels are therefore renewable energy sources. Most biofuels are produced from the cellulose in plant cell walls. Since the global need for energy is increasing, biofuel production could have huge economic benefits. Also, since plants use carbon dioxide gas from the atmosphere during photosynthesis, there is some evidence that large-scale biofuel production could reduce atmospheric levels of carbon dioxide, slowing the rate of climate change. However, this evidence is far from conclusive, and the projected net carbon balance of biofuel production and use remains controversial. Given the demand for alternative fuels and the potential benefits, many researchers are investigating plants that have high photosynthetic rates as a source of biofuel. One example is Miscanthus grass, shown in **Figure 1**.

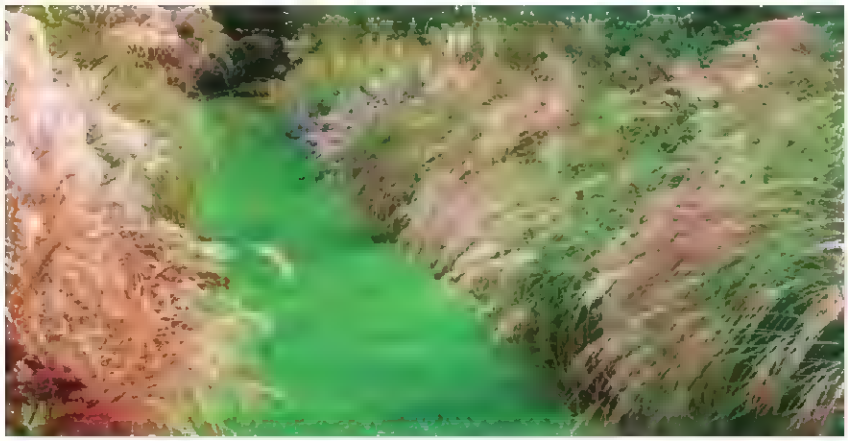


Figure 1 Miscanthus is a tall grass species that is often grown as an ornamental plant, as in this garden. Researchers have found that Miscanthus has a higher rate of photosynthesis than other grasses, which makes it a good candidate for biofuel production.

The Issue

At first look, biofuels may appear to be an energy source that benefits people and the environment. However, these potential benefits depend on the species of plants that are used, and how and where they are grown. For example, some people are concerned that if agricultural land is used to grow plants for biofuels, less land will be used to grow food crops, and thus food prices will increase. If the plants are grown by monoculture, biofuel production would reduce biodiversity and increase the use of fertilizers and irrigation, which would not benefit the environment. Others worry that only wealthier nations will be able to afford to use land for biofuels, and less-developed nations will be left behind. Advocates for biofuel production counter that poor countries cannot afford costly imported petroleum but do have the ability and the right to grow their fuel.

CAREER LINK

International Development

International development involves finding ways to use resources in a way that sustains both people and the environment, often in developing countries. To find out about some of the paths to a career in international development,

GO TO NELSON SCIENCE

Role

You are a member of a think tank that focuses on alternative energy sources. Your think tank will be attending a conference to discuss the costs and benefits of using land to grow biofuels in Canada.

Audience

Your audience will be the other conference members, made up of government officials, farmers, agricultural companies, fuel manufacturers, and environmentalists.

Goal

To prepare a multimedia presentation, suitable for a conference, that presents the facts for and against using more land in Canada to grow plants for biofuels

WEB LINK

To start your research on the costs and benefits of biofuels,

GO TO NELSON SCIENCE

Research

Carry out research to find out more about the costs and benefits of using land for growing biofuel plants in Canada.

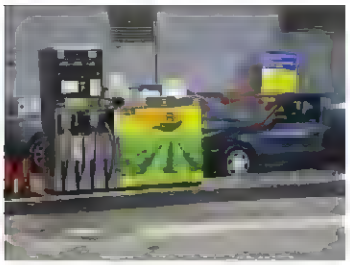


Figure 2 Could biofuels be offered at all gas stations?

Identify Solutions

You may wish to consider the following:

- What type of biofuel plant(s) should Canada try to grow, if any?
- What technology or infrastructure is needed to produce and distribute biofuel made from the plants (**Figure 2**)?
- What are the economic benefits of biofuel production and potential energy independence?
- Would any parts of the agricultural sector suffer if biofuels were widely grown?
- Who will receive the profits from growing biofuel plants?
- Will people be willing to pay more for food if food prices increase as a result of using arable land to grow biofuels?
- Could any of the potential biofuel plants be grown in a sustainable way?

Make a Decision

Based on your research, decide in your group whether you will argue for or against using land for growing biofuels in Canada.

UNIT TASK BOOKMARK

You can apply the skills you learn in conducting a cost–benefit analysis as you complete the Unit Task.

Communicate

Prepare a multimedia presentation that shows your group's decision and the reasons behind it. You may choose to use presentation software or social media, make a web page, or make an oral presentation.

Plan for Action

Although biodiesel has some environmental negatives, in the short term using biodiesel may reduce the demand for oil. If all transport trucks were to use biodiesel instead of diesel manufactured from crude oil, there would be less demand for new oil wells. That might also mean fewer events such as the deep-water leak in the Gulf of Mexico or the pipeline leak in the eastern United States that also happened in 2010. A major barrier to widespread use of biodiesel is that there are few service stations that supply it.

Create a plan to make transport companies and fuel service stations more aware of this alternative fuel. You may wish to draft a letter to a paper or trade magazine, prepare a video report that could be aired on your local community TV station, or design a billboard. Find a way to get your message across in a positive way!

GO TO NELSON SCIENCE

Plant Growth and Development

13.5

Figure 1 shows the remarkable plant commonly known as the walking palm tree. The walking palm requires high amounts of sunshine. When environmental conditions change so that the walking palm is in the shade, it responds in a way that moves the plant to a sunnier site. The projections from its trunk that you see in Figure 1 are adventitious roots. The walking palm always grows more adventitious roots on stems that receive more sunlight. In contrast, any adventitious roots on shaded roots die off. The growth and loss of the adventitious roots moves the stems and leaves so that the entire plant appears to walk toward sunlight. This is an amazing example of how plants respond to changes in their environment.

In order to produce new roots, cells in the palm stem must undergo both growth and differentiation. **Growth** is simply the process of increasing in size, much like blowing up a balloon. **Differentiation** is the process by which a cell becomes specialized to perform a particular function. For the walking palm to move, cells in the stem must differentiate to form all the cell types found in a mature adventitious root.

Figure 1 The walking palm is found in Costa Rica, as well as in other parts of Central America.

growth the process of cell enlargement

differentiation the process of cell specialization

apical meristem plant tissue composed of actively dividing cells; responsible for primary growth and located at the tip of the root(s) and shoot(s) of a plant

primary growth plant growth originating from the apical meristems throughout the life of the plant; results in increases in length and any growth in the diameter of stems and roots that occurs in the first year

secondary growth growth that occurs from lateral meristems and results in an increase in girth

lateral meristem (cambium) plant tissue consisting of actively dividing cells that produce secondary growth

Types of Growth

Unlike most animals, most plants continue to grow in height for their entire lives. The increase in height comes from **apical meristems**, which are regions of actively dividing cells found at the apices (tips) of plants. Most plants have apical meristems at the tips of their buds, stems, and roots. All growth from the apical meristems is called **primary growth**. Primary growth always increases the height of a plant, but not its width. In contrast, **secondary growth** is growth that arises from **lateral meristems**, which are areas of actively dividing tissue in the stems and roots. Secondary growth increases the girth (width) of a plant. Some plants do not have lateral meristems, and those plants do not undergo secondary growth. **Figure 2** shows the general locations of primary and secondary meristems in a typical woody plant.

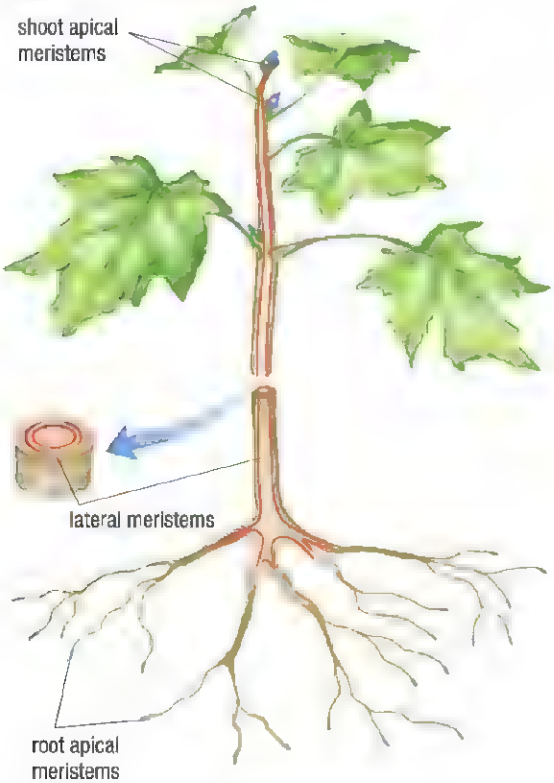


Figure 2 Apical meristems are found at the tips of roots and in shoot buds, and lateral meristems are found mainly in the stems of woody plants.

Primary Growth

Primary growth increases the length of a plant shoot or root. It begins as the cells of the apical meristems divide by mitosis (**Figure 3**). Cell division increases the number of cells. Once cell division has occurred, each cell grows longer. The elongated cells then begin to become specialized (differentiate) into different cell types, such as parenchyma, epidermal, or vascular cell types.

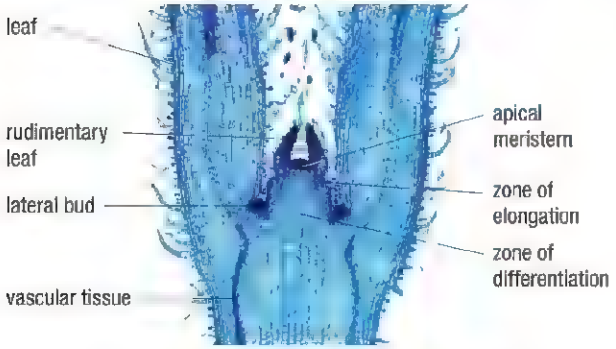


Figure 3 In the shoot, cells in the apical meristems divide; then the newly formed cells elongate and begin to differentiate.

The shoot apical meristem produces the tissues that form stems, leaves, and the organs responsible for sexual reproduction, such as flowers in angiosperms. The differentiation of a cell is, in part, determined by the cell's location. For example, cells on the outermost part of the shoot become epidermal cells, and some of the inner cells will become vascular tissue.

The root apical meristem produces the cells of the root cap and all other cell types in the root. The zones of cell division, elongation, and differentiation (also known as maturation) are more clearly defined in the root (**Figure 4**). The root cap protects the meristem as the root pushes through the soil. Most of the increase in a root's length happens in the zone of elongation. Cell elongation can push the root cap and apical meristem through the soil as much as several centimetres a day.

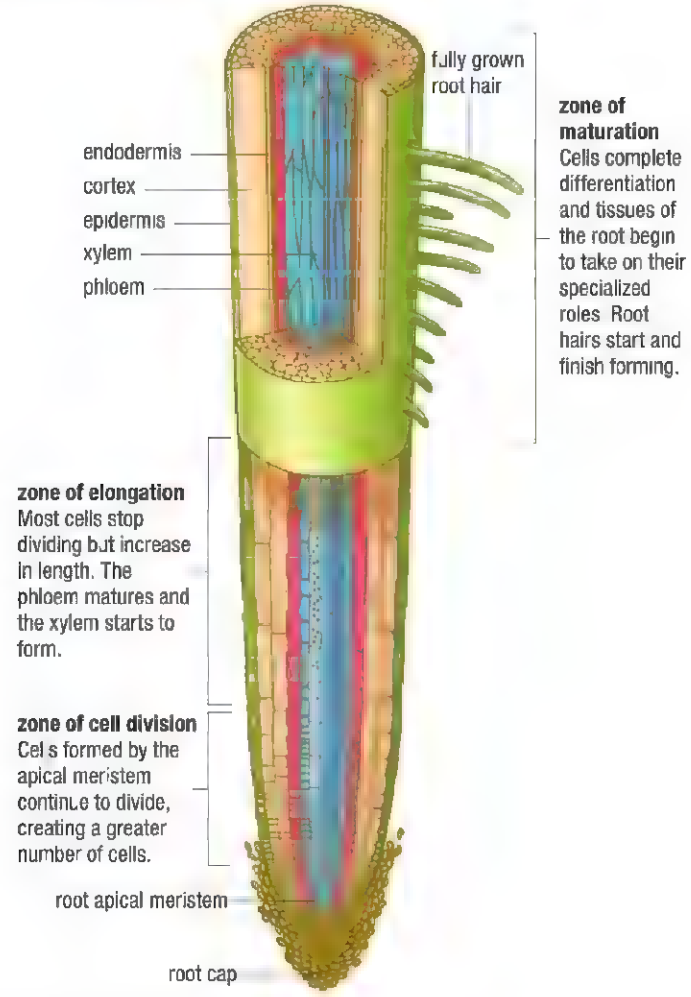


Figure 4 Primary growth from a root apical meristem

All tissue formed from apical meristems is called primary tissue. For example, phloem and xylem that arise from an apical meristem are called primary phloem and primary xylem. As you will see, this helps to distinguish this tissue from tissue produced by lateral meristems.

Secondary Growth

Secondary growth only happens in woody species after the plant's first year. Wood is a product of secondary growth. Secondary growth arises from a lateral meristem, and all tissues that are formed by it are called secondary tissues. Lateral meristems are never at the apex of the shoot or root. Vascular cambium is an example of a lateral meristem. It gives rise to secondary phloem and secondary xylem cells.

After the first year of growth, primary and secondary growth happen simultaneously (**Figure 5**). Woody species continue primary growth and increase in length (height). They also increase in diameter through secondary growth from two lateral meristems. One is the cork cambium, which produces the cells that form the bark. The other is the vascular cambium, which produces secondary xylem and phloem. Vascular cambium is found between the phloem and the xylem in the stem. Each cell division in the vascular cambium produces one new xylem cell and one new phloem cell.

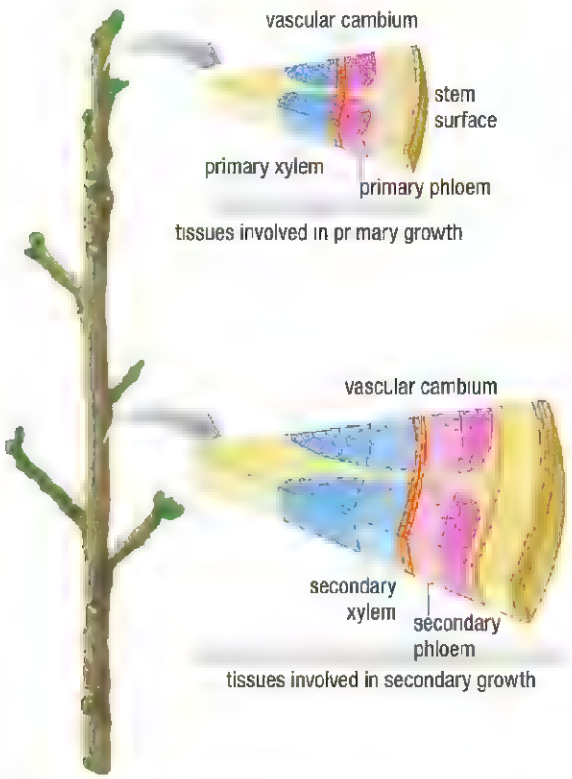


Figure 5 Primary and secondary growth in a woody stem

Each year, the vascular cambium produces new secondary xylem and phloem. The secondary vascular tissue eventually crushes the primary phloem. The amount of growth will vary from year to year depending on the environmental conditions. These variations in environmental conditions produce growth rings of varying thickness that we see in the cross-section of a tree (**Figure 6**). Thus, growth rings can provide valuable information about past climate conditions in a region. A growth ring from a dry year will be a lot thinner than a growth ring from a rainy year. Secondary growth (and thus growth rings) also occurs in roots of woody species.

Figure 6 Growth rings in a conifer tree. Each growth ring consists of a light band and a dark band.

CAREER LINK

Plant Physiologist

Plant physiologists conduct research on many aspects of plant growth and development, including how plants respond to environmental factors. To find out more about a career as a plant physiologist

GO TO NELSON SCIENCE

Environmental Factors That Affect Plant Growth and Differentiation

The walking palm in Figure 1 is an unusual example of how the environment can affect plant growth. All plants respond to changes in their environment in some way. The main environmental factors that affect plant growth and development are light, water, temperature, and nutrient availability. These factors vary naturally across our planet. The presence of plants and other organisms can change these factors for individual plants, as occurs in succession. Human activity can also change these factors. For example, plants growing in a greenhouse will experience very different environmental conditions than plants growing outside the greenhouse.

Light

You may have seen plant "grow lights" for sale at hardware stores or aquarium stores. Without these special lights, indoor plants may become pale and elongated. Why? We know that plants use the energy in sunlight for photosynthesis. Sunlight is actually a spectrum of different wavelengths of light, each with a different energy level (**Figure 7**). In the visible range of the spectrum, we see these different wavelengths as different colours of light. The "grow bulbs" emit light at wavelengths that promote desirable plant growth.

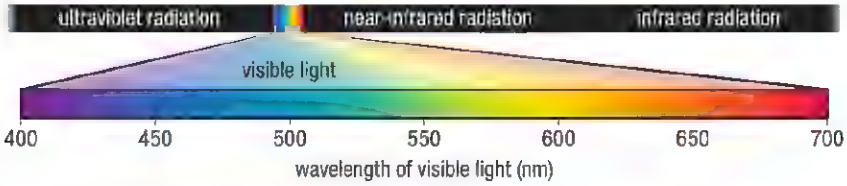


Figure 7 The spectrum of wavelengths in sunlight

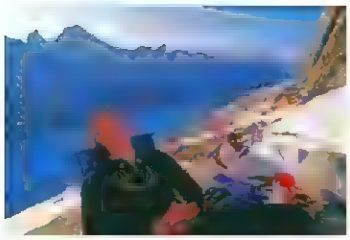


Figure 8 Hikers enjoy the midnight sun on Baffin Island, Nunavut. This picture was taken in late June at about 1:00 or 2:00 a.m.

photoreceptor a molecule that detects light; different photoreceptors detect different wavelengths of light

In any environment, the particular wavelengths of light (light quality) that reach a plant will vary. For example, the wavelengths that reach a plant at high noon will be different from those reaching the same plant in the early evening. The intensity (brightness) and length of the day also vary. In regions with seasons, such as Canada, light conditions change significantly during the year. Because indoor light levels are typically much lower than outdoor light levels, our houseplants are very shade-tolerant species.

SEASONAL CHANGES IN LIGHT

The farther a place is from the equator, the more dramatic are the changes in light quality and quantity throughout the year. In Canada's Arctic regions, for example, there is continual darkness from October to March, but continual sunlight in the summer months (**Figure 8**). As the day length changes, the wavelengths of light that reach Earth's surface also change. Plants are able to detect changes in the light conditions through molecules called photoreceptors. A **photoreceptor** is a molecule that reacts when struck by light of a certain intensity and/or wavelength. Different photoreceptors react to light of different wavelengths. As day length changes, the ratio of red light (660 nm wavelength) to far-red light (730 nm wavelength) received at Earth's surface also changes. Photoreceptors respond to this change, and this signals the plant to change its growth and/or development.

Many developmental changes in plants are regulated by light. For example, photoreceptors play an important role in the changes in deciduous trees we see each spring and fall. The seeds of some plants, such as lettuce, require specific light conditions to germinate. Other seeds, such as those of many lilies, will not germinate in the presence of light.

PHOTOPERIODISM

photoperiodism a plant's response to changing day length

Photoperiodism is a plant's response to changes in day length. In some species, timing of flowering is an example of photoperiodism. For example, tulips and chrysanthemums often only initiate flowering when days are short (under 12 h). Plants that

flower only when days are short are called short-day plants. Other plants, such as spinach, are long-day plants and flower only when there are 12 h or more of daylight. In other species, such as tomato and rose plants, flowering is not affected by day length at all. These are called day-neutral plants.

Photoperiodism can ensure that a plant flowers only when other environmental conditions are likely to be best for reproduction. It may ensure that a plant flowers when its pollinators are present or when there is likely to be a lot of rain, such as in spring. Photoperiodism can also determine where a plant can survive. A long-day plant, such as spinach, would never flower near the equator, because the days are never long enough.

Nutrients

Plants do not need to "eat" food. Instead, plants assemble all of their own carbohydrates, fats, proteins, and other needed molecules from simple inorganic substances. These simple inorganic substances are referred to as plant nutrients and must be obtained from the environment. There are two categories of plant nutrients: macronutrients and micronutrients. **Macronutrients** are nutrients that are needed in larger quantities (more than 1000 mg/kg of dry mass). Nitrogen (N), phosphorus (P), and potassium (K) are macronutrients. Farmers and gardeners often add these nutrients to soil by applying fertilizer. The numbers you see on bags of fertilizer refer to the relative concentrations of these three nutrients (**Figure 9**).

macronutrients plant nutrients needed in large quantities

Table 1 lists plant macronutrients and the symptoms of nutrient deficiency. Note that the first three macronutrients in Table 1 are absorbed from the gases in the atmosphere (carbon and oxygen) or are obtained from water itself (hydrogen and oxygen). The remaining nutrients are obtained as dissolved ions from water in the soil and are taken up by the plant's roots. **Figure 10** shows a plant suffering from chlorosis, which is yellowing of older leaves. This is a symptom of either nitrogen or magnesium deficiency.

Figure 9 The numbers on these bags of fertilizer refer to the percentage of nitrogen, phosphorous, and potassium, in that order.

Figure 10 The chlorosis of the leaves of this canola plant is due to nitrogen deficiency.

Table 1 Plant Macronutrients and Their Functions

Element	Commonly absorbed forms	Some known functions	Some deficiency symptoms
carbon (C)	CO_2	synthesis of all organic compounds	rarely deficient; available from the atmosphere
hydrogen (H)	H_2O	synthesis of all organic compounds	available from water; incapable of growth without it
oxygen (O)	CO_2, H_2O, O_2	release of energy through cellular respiration	available from the atmosphere and as a product of photosynthesis; cells die without it
nitrogen (N)	NO_3^-, NH_4^+	production of proteins, nucleic acids, chlorophyll	stunted growth, chlorosis
phosphorus (P)	$H_2PO_4^-$, HPO_4^{2+}	production of nucleic acids, membranes	purplish veins, stunted growth, fewer seeds or fruit
potassium (K)	K^+	activation of enzymes, cellular transport mechanisms	reduced growth, curled or spotted older leaves, burned leaf edges
calcium (Ca)	Ca^{2+}	formation and maintenance of cell walls; membrane transport mechanism	deformed leaves, poor root growth, death of buds
sulfur (S)	SO_4^{2-}	production of proteins	pale green leaves or chlorosis, slow growth
magnesium (Mg)	Mg^{2+}	production of chlorophyll; activation of enzymes	chlorosis, drooping leaves

micronutrients plant nutrients needed in small quantities

Micronutrients are nutrients that plants need in only very small amounts (less than 100 mg/kg of dry mass). There are eight micronutrients: boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc. These nutrients are involved in a wide range of cellular processes, including chlorophyll synthesis, cell division, and enzyme production.

Research This

The Three Sisters

Skills: Researching, Analyzing, Evaluating, Communicating, Identifying Alternatives, Defending a Decision

SKILLS HANDBOOK A5.1

The Iroquois peoples in North America protected the nutrient content of the soil they used for agriculture by growing certain plants together. The best known of these were called the three sisters: squash, corn, and beans. Each of these species supported the growth of the other in a certain way. These three species also supplied much of the nutrients needed to support the human population.

1. Working in a group, find out how the three sisters were grown and what role each of the plants played (**Figure 11**).

A. How did the three sisters help maintain the soil? T/I

B. Did growing the three sisters together have any other advantages? T/I

C. Describe how you could plant a three sisters garden. T/I A C

D. The three sisters are an example of companion planting. Find a general definition for companion planting. T/I

E. Do you think people should use companion planting in their gardens? Explain why or why not. T/I A

Figure 11 The three sisters

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Temperature

The rate of all cellular processes is affected by temperature. In general, there is a specific temperature range at which these processes perform best. The opening and closing of the stomata are affected by temperature. Transpiration is highest on hot sunny days when the stomata are open (**Figure 12(a)**). If the plant cannot pull enough water from the soil to replace the water lost through transpiration, it will start to wilt. To prevent excess water loss, the stomata close (**Figure 12(b)**). If the temperature is above or below the plant's optimum range, the plant will grow more slowly.

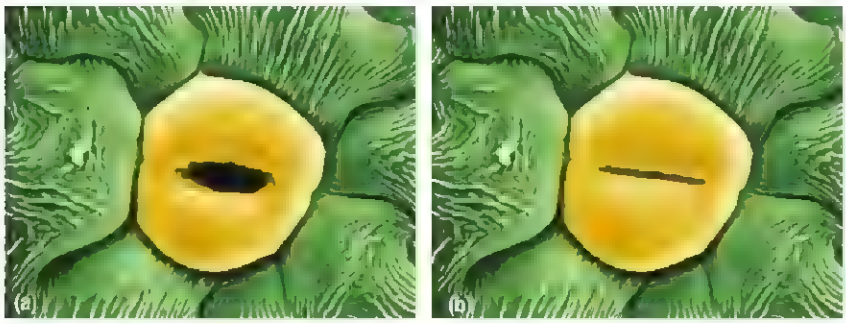

Figure 12 (a) An open stoma allows water vapour to leave the leaf. (b) A closed stoma prevents transpiration from occurring.

For many plants, temperature also acts as a signal to begin a developmental stage. For example, the seeds of many tree species, such as loblolly pine, will germinate only after undergoing a period of cold treatment (**Figure 13**). This requirement increases the chances that the seed will germinate in the spring, when there is a greater chance that the seedling will survive.

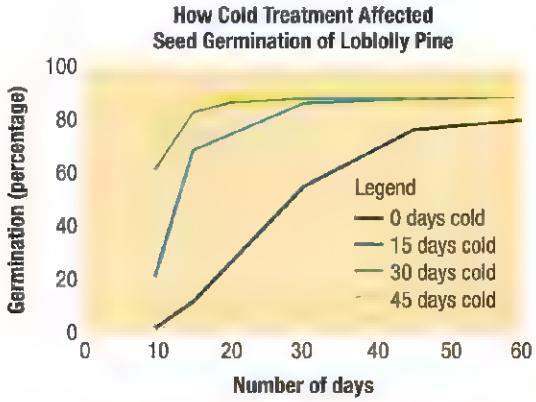

Figure 13 In this experiment, seeds of loblolly pine were moistened and then stored at 4 °C for 0 to 45 days. They were then left at room temperature for 60 days. The number of seeds that germinated over the 60 day period was counted to get the percentage germination.

The timing of the flowering of many angiosperms is affected by temperature. This increases the chance that flowering occurs when environmental conditions will support seed formation. For example, species that depend on pollinators must be in flower when their pollinators are present. If these species flower too early or too late for their pollinators, they will be unable to produce fertile seeds.

CLIMATE CHANGE

Earth's average temperature has increased over the last century and is predicted to increase further. This increase is mainly due to human activity. In 2010, scientists analyzed 400 000 records of first flowering dates from 405 angiosperm species in the United Kingdom. They found that for every 1 °C increase in temperature, flowering occurred five days earlier, on average. Over the last 25 years, flowering occurred 2.2 to 12.7 days earlier than in any previous 25 year period since 1760. Earlier flowering can break the link between flowering date and the appearance of insect or bird pollinators. For example, the serviceberry is a common flowering shrub in Ontario and an important source of food for many wildlife species (**Figure 14**). It relies on photoperiod to time its flowering. Unlike many other species, temperature does not influence when it flowers. The serviceberry used to be the first shrub to flower in spring. But because average temperatures have risen, today other plants flower at the same time as the serviceberry does, so it has to compete for pollinators.

Soil

Soil plays three roles: (1) it provides a medium in which plant roots can anchor, (2) it retains water, in which nutrients are dissolved, and (3) it provides the root with air. The characteristics of soil can dramatically affect plant growth and development. Soil that is very sandy does not hold water well, so it dries out quickly. Soil with too much clay does not have many air spaces and holds too much water, which can cause the plant to drown. Soil must also have sufficient humus. Humus is organic matter made up of the partially decomposed remains of organisms. Humus is the main source of many nutrients needed by the plant, particularly nitrogen. These nutrients are released by the action of soil micro-organisms and fungi.

Investigation 13.5.1

Temperature, Light, and Seed Germination (page 620)

After reading about seeds, you can complete Investigation 13.5.1.

In this controlled experiment you will investigate how radish seeds germinate under different conditions.

Investigation 13.5.2

Factors Affecting Plant Growth and Differentiation (page 621)

Now that you have learned about some of the factors that influence plant growth, you may want to do Investigation 13.5.2.

In this student-directed controlled experiment you will choose an environmental factor and investigate its effect on plants.

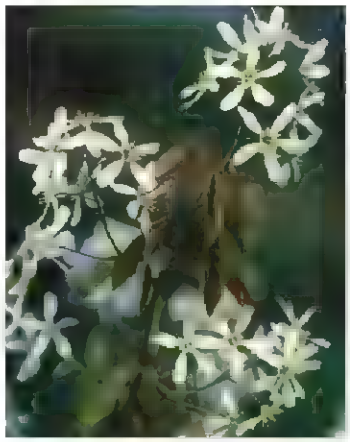

Figure 14 Climate change means the serviceberry must compete for pollinators.

Figure 15 Plants can be grown without soil. These cucumber plants are growing in a nutrient solution.

The pH of soil also affects plant growth and development. Soil can be acidic (low pH), basic (high pH), or neutral (pH of 7.0). The pH of soil really refers to the pH of the water in the soil. Soil pH determines whether the macronutrients and micronutrients will dissolve in the soil water and be in a form that can be taken up by the roots. Most plants prefer mildly acidic soil.

However, soil is not necessary for a plant to survive. Commercial growers sometimes produce plants in mixtures that include no soil, or even in nutrient solutions (**Figure 15**).

13.5 Summary

- Growth is a change in the number and size of cells. Differentiation is a change in the function of a cell (specialization).
- Primary growth arises from cell division in apical meristems. Secondary growth arises from lateral meristems.
- The quality, quantity, and timing of light affect growth and development in many plants.
- Healthy plant growth and development depend on specific macronutrients and micronutrients.
- Temperature affects the rate of growth and also promotes or inhibits particular stages of development in many plants.
- Soil characteristics and the pH of soil water affect plant growth and development.

13.5 Questions

1. In your own words, write definitions for the following terms: growth, differentiation, primary growth, secondary growth, apical meristem, lateral meristem K/U C
2. During an investigation, a student makes a cross-section of root in the region close to the tip that has no root hairs. Predict the cell and tissue types the student will see. Give reasons for your predictions. K/U T/I A
3. What are the three most important nutrients for plant growth? K/U
4. Compare and contrast primary and secondary growth in a woody stem. K/U A
5. Most commercial fertilizers contain only macronutrients. Why? K/U
6. The leaves on a plant in your garden begin to turn yellow. From this observation alone, can you predict which nutrient the plant lacks? Explain. K/U A
7. Over the last 30 years, there has been a relatively modest increase in the acidity of soil water (due to acid rain). However, scientists have found a significant decrease in the growth of forests around the world. Form a hypothesis as to why this is happening. K/U A
8. Soil pH can vary considerably, and air pollution in the form of acid rain can alter the pH of soils. Use the Internet and other sources to determine the ideal soil pH for a variety of different plant species. Report your findings to the class. T/I C
9. Organic farmers use a variety of sources of nutrients to maintain healthy soil. Visit a local garden centre or go online to find out what sorts of organic fertilizers are available. What might be some advantages and disadvantages of using these fertilizers? T/I A
10. In 2008, heat and drought in the Black Sea region of Eastern Europe caused widespread crop loss, such as the sunflower crop shown in **Figure 16**. These conditions caused a huge increase in the price of many food staples in the region. Which do you think caused the most crop damage: the increase in temperature or the lack of water? Explain. Was the increase in food prices caused entirely by the crop failure? K/U A

Figure 16 A damaged sunflower crop in the Black Sea region

GO TO NELSON SCIENCE

13.6

Control of Plant Growth and Development

The tree growing from a cliff shown in **Figure 1** seems to be defying gravity. However, its growth and development are, in fact, responding to gravity. It is vitally important for all plants to be able to grow in the correct orientation, so that the shoot grows toward sunlight and the roots grow down into the soil. In this section you will explore how plants can modify their development in response to the environment.

Figure 1 Despite being on a cliff, this tree still grows upward and its roots grow downward.

Plant Growth Regulators

The body shapes of plants can change as they grow and vary from individual to individual. Since plants cannot change location, this adaptation allows plants to respond to changes in the environment. For example, a plant grown in very low light looks dramatically different than one grown in full sunlight (**Figure 2**). In contrast, your body shape remains unchanged if you have had little exposure to light, although your health might suffer.

Plants are able to modify their growth and differentiation through the action of chemicals called **plant growth regulators**. In general, plant growth regulators act by signalling plant cells to undergo particular changes. Scientists have identified a number of plant growth regulators, and there may still be more. In this section you will explore five plant growth regulators that are found in most plants: auxins, gibberellins, cytokinins, ethylene, and abscisic acid.

Plant growth regulators have a number of effects on plant growth and differentiation. You will see that their effects depend on the type of tissue and the developmental stage of the plant. In addition, evidence shows that plant growth regulators also influence one another and are influenced by environmental factors. The action of plant growth regulators is a very active field of study.

Figure 2 Lack of sunlight has caused the plant on the right to grow in a tall and spindly manner.

plant growth regulator a chemical produced by plant cells that regulates growth and differentiation

tropism a directional change in growth or movement in response to a stimulus

phototropism a change in direction of a growing plant in response to light

Tropisms and Plant Growth Regulators

A **tropism** is a change in the direction of growth or movement of a plant in response to a stimulus. Tropisms are controlled by plant growth regulators. The existence of plant growth regulators was first hypothesized by Charles Darwin and his son Francis when they were investigating a tropism. They were attempting to explain why seedlings grown in a sunny window bend toward the light. This is called **phototropism**, which is a change in the direction of growth of a plant in response to light. The plant is detecting, and responding to, uneven lighting in its environment.

The Darwins carried out several experiments with a monocot grass species. These are summarized in **Figure 3**. In the first experiment they removed the shoot tip of some of the plants. When placed in a sunny window, plants with the tip bent toward the light, but those without the tip did not (**Figure 3(a)**). The Darwins concluded that the tip might produce a substance in response to the light. However, cutting off the tip might have damaged the plant so that it could not grow normally. Therefore, they carried out a second experiment. Instead of cutting off the shoot tips, they covered one with an opaque cap and one with a translucent cap. Light could pass through only the translucent cap. As demonstrated in **Figure 3(b)**, only the plants with translucent caps bent toward the light. The Darwins concluded that when a seedling is illuminated from one side, an unknown factor is transmitted from the seedling's tip to the tissue below, which causes it to bend toward the light.

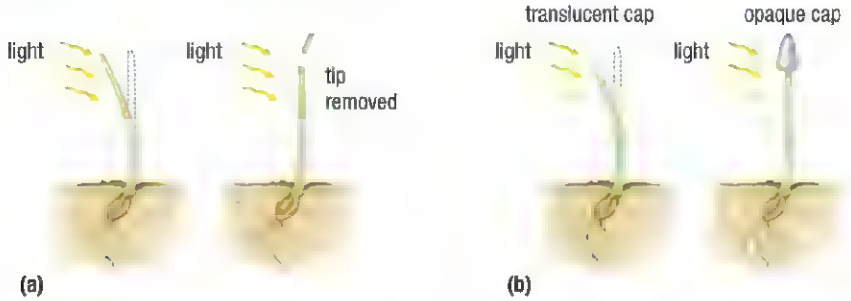

Figure 3 Darwin's phototropism experiments led him to hypothesize that plants produce substances that regulate their growth. (a) Plants with intact tips bend toward light, while plants with tips removed do not. (b) When the tip is covered with an opaque cap that blocks light, the seedling does not bend. When the cap is translucent and allows light to pass through to the tip, the seedling bends.

gravitropism a directional change in growth pattern in response to gravity

thigmotropism a directional change in growth pattern in response to touch

WEB LINK

To view animations of plant tropisms,

GO TO NELSON SCIENCE

There are several other types of tropism. **Gravitropism** is a change in the direction of growth in response to gravity. The tree in Figure 1 (page 613) shows gravitropism. When a seed germinates, gravitropism causes the emerging root to grow downward and the emerging shoot to grow upward. If a bulb is planted upside down, the roots and shoots will still grow in the correct direction. However, the plant may run out of stored energy before the shoot emerges from the ground. This is why packaged bulbs usually have a diagram to show the correct way to plant.

Some plants show **thigmotropism**, which is a change in the direction of growth in response to contact. Climbing vines, such as beans and peas, often show thigmotropism (**Figure 4(a)**). Plants carry out all of these tropisms (**Figure 4(b)**).

Figure 4 (a) The tendrils on this pea plant are modified leaves that show thigmotropism. (b) Thigmotropism and gravitropism help this banyan tree support itself.

Auxins

Auxins are a group of compounds that act in similar ways on plant growth and cell differentiation. The shoot apical meristem is the main site of auxin synthesis. The primary role of auxins is to promote cell elongation. The unknown substance that the Darwins thought the tip of a growing seedling produced is auxin. Scientists have since shown that during phototropism, the side of the plant closest to light contains less auxin than the side shaded from the light. As a result, the cells on the shaded side are stimulated to elongate. The relative difference in cell size causes the stem to bend (**Figure 5**). As a result, the plant maximizes the amount of light it receives.

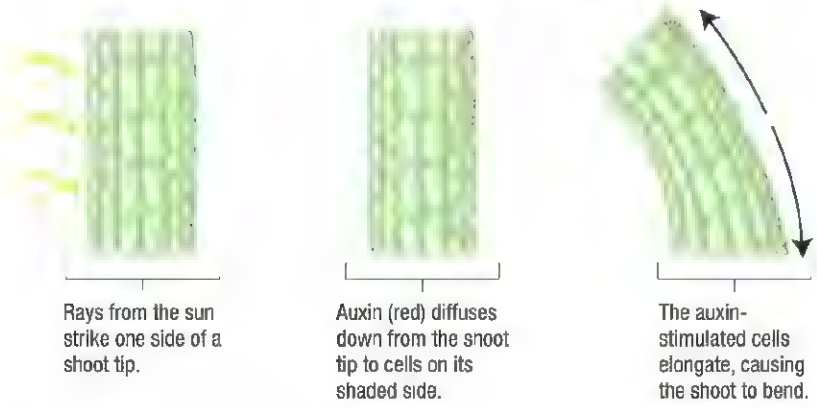

Figure 5 The effects of auxin on cells

When plants are commercially grown indoors, artificial lighting is usually placed directly overhead to avoid phototropism. This ensures that plants have thicker, straighter stems (**Figure 6**).

Some herbicides contain auxins that cause plants to undergo cell elongation at an unsustainably rapid rate. The rapid growth causes them to outstrip their carbohydrate supply, run out of energy, and die. Synthetic auxins may also be used by commercial fruit growers to induce cell elongation in fruits. By spraying an orchard with an auxin solution, fruit ripening can be artificially synchronized in all the plants. This reduces the cost of harvesting the fruit, because most of the fruit can be picked at one time. Growers therefore do not have to pay pickers to pick several times.

Figure 6 The plants in this growth room do not show phototropism because the lighting is directly overhead

Auxins also inhibit cell division in some tissues. The best known example of this occurs in apical dominance. In **apical dominance**, cell division occurs in the apical bud but is inhibited in the lateral buds. Apical dominance is caused by the high level of auxin released by the apical meristem. Growers often stop apical dominance by cutting off the apical bud. This removes the main source of auxin and causes the lateral buds to develop. The resulting plant is shorter and has more branches than if the apical bud had not been removed. A grower can cause a plant to produce more flowers, fruit, or leaves by removing the apical bud. For example, basil plants can be made bushier by removing the apical bud at the end of each stem (**Figure 7**).

apical dominance the condition in which most shoot growth arises from the apical bud and not lateral buds

Auxin also stimulates cell division in the vascular cambium and promotes the formation of new lateral meristems and new root apical meristems. Auxins are therefore included in rooting compounds, which are used to induce the formation of new root meristems from plant cuttings. Auxin also helps to regulate gravitropism.

Figure 7 An apical bud on a basil plant (centre). Removing the apical bud results in more branching and more leaves.

Figure 8 Gibberellin has been shown to stimulate the rapid stem elongation that happens when plants, such as these lettuces bolt.

Gibberellins

Gibberellins are a family of compounds that share a similar chemical structure and act in similar ways in plant cells. To date, more than 100 different gibberellins have been identified. Gibberellins play a role in many different growth and differentiation processes. High levels of gibberellins are produced by young tissues of shoots and by developing seeds, but leaves and young roots may also produce them.

The action of gibberellins is highly variable. Gibberellins promote cell division and cell elongation, depending on the tissue they are affecting. Environmental factors can also modify the effect of gibberellins on different plant tissues. However, gibberellins do appear to have a strong effect on the size of a plant. Many dwarf plant varieties are small because they produce very low levels of gibberellins.

Gibberellins also play a role in flowering and fruit production in many species. In fact, grape growers sometimes spray their crops with a gibberellin solution to induce fruit production. The gibberellin spray also causes the fruit stems to elongate, which gives more space for each individual grape to grow. As a result, individual grapes are larger. This makes grape bunches much larger and more appealing to buyers.

Studies have shown that gibberellins help make stored carbohydrate reserves available to the growing embryo. They also play a role in the response of plants to temperature changes. For example, when plants such as cabbage and lettuce experience a cold period, they bolt and go to seed. Bolting is rapid stem elongation that happens prior to flowering in some species (**Figure 8**). Seed producers may induce bolting by spraying plants with gibberellins.

Cytokinins

Cytokinins share a similar chemical structure, and they all promote cell division. They are found in tissues that are actively dividing, such as meristems, young leaves, and growing seeds. Cytokinins help to stimulate cell division in lateral buds when an apical bud has been removed. The effect of cytokinins on plant tissues depends on the presence of other plant growth regulators. The normal development of shoots and roots in a growing plant is regulated by the interaction of cytokinins and auxins.

Cytokinins also slow cell aging in certain plant organs by inhibiting protein breakdown and stimulating protein synthesis. Synthetic cytokinins are commonly sprayed on lettuce and mushrooms to keep them from spoiling. This effect may be related to inhibiting the effects of ethylene, another plant growth regulator.

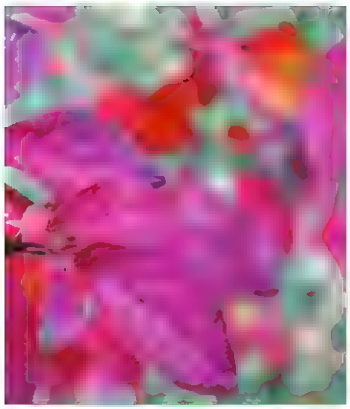

Figure 9 Ethylene plays a role in senescence, including the leaf drop that occurs in the fall.

senescence developmental events in a plant tissue or organ from maturity to death

Ethylene

Ethylene, a gas, is a plant growth regulator that is produced by plants at various stages of development. Ethylene is sometimes called "the plant stress hormone" because it induces changes that protect a plant against environmental stress. For example, ethylene stimulates plants to lose their leaves in drought conditions. Recent studies suggest ethylene may have a role in the responses of plants to human-made environmental stresses. For example, an increase in ozone, an air pollutant, reduces crop yields. Recent studies show that an increase in atmospheric ozone increases ethylene production in plants. Ethylene also regulates the growth of roots and shoots around obstacles. For example, if a root touches a stone, the roots cells are stimulated to produce ethylene, which causes the root to grow sideways. When root cells no longer touch the stone, ethylene is no longer produced and the root grows downward again. Ethylene is also released at the site of a wound on a plant.

Ethylene also stimulates many developmental stages. These include fruit ripening, shoot and root growth and differentiation, flower opening, leaf and fruit drop (release from the stem), and flower and leaf senescence. **Senescence** refers to development processes that occur between maturity and death (**Figure 9**). As with the other growth regulators, the particular effect of ethylene depends on the species, the tissue or organ, and the levels of other plant growth regulators.

The role of ethylene in fruit ripening has great economic importance. Fruits release ethylene as they ripen, which induces further ripening and, eventually, spoilage. Fruit producers therefore try to control ethylene levels from the time a fruit is picked to when consumers buy it in the supermarket. To prevent ethylene production, producers ship fruit in well-ventilated trucks that contain ethylene-absorbing filters. Produce that is particularly sensitive to ethylene, such as broccoli, cabbage, and lettuce, is shipped separately from high ethylene producers, such as apples, bananas, and tomatoes. Ethylene may also be released into airtight shipping containers so that the produce all ripens at the same time. This helps the produce sell more readily. At home, you can ripen fruit by enclosing it in a plastic bag with a ripe banana. Ripe bananas produce high levels of ethylene.

Abscisic Acid

The primary role of abscisic acid (ABA) is to inhibit growth. ABA levels rise in response to changes in temperature and light, such as those occurring with the changing seasons. ABA maintains dormancy in leaf buds and seeds. Dormancy is a period of time when a plant or seed does not grow (**Figure 10**).

Dormant plants are less vulnerable to damage than actively growing plants. This is one reason why deciduous trees are dormant over winter and why grasses become dormant and turn brown during hot, dry periods in summer. ABA is sometimes applied to plants before they are shipped from nurseries to garden centres for the same reason. Once the plants have reached their destination, the ABA-induced dormancy can be reversed by spraying the plants with a gibberellin spray.

Another important role of ABA is to control the closing of stomata when the environment is dry. When they have insufficient water, plants wilt. Wilting induces mesophyll cells in the leaf to produce ABA. This ABA diffuses to the guard cells of the stomata and induces them to close, allowing the leaves to conserve their internal water.

Figure 10 ABA keeps buds dormant until the right light and temperature conditions exist to support their growth.

Using Plant Growth Regulators in Plant Tissue Culture

Plant tissue culture is a technology that can be used to produce many clones of plants with desirable traits. **Figure 11** shows a common procedure in plant tissue culture. Each bumpy mass of shoots you see on the Petri dish was produced from a tiny stem segment taken from an intact plant. How? First, the scientist placed the stem segment on a tissue culture medium containing plant growth regulators that induced the cells to divide. Once its cells started to divide, the stem segment was moved to a culture medium containing plant growth regulators that induced shoot differentiation.

CAREER LINK

Lab Technician

Lab technicians may work in institutions or companies that are involved in plant tissue culture. For more information about a career as a lab technician,

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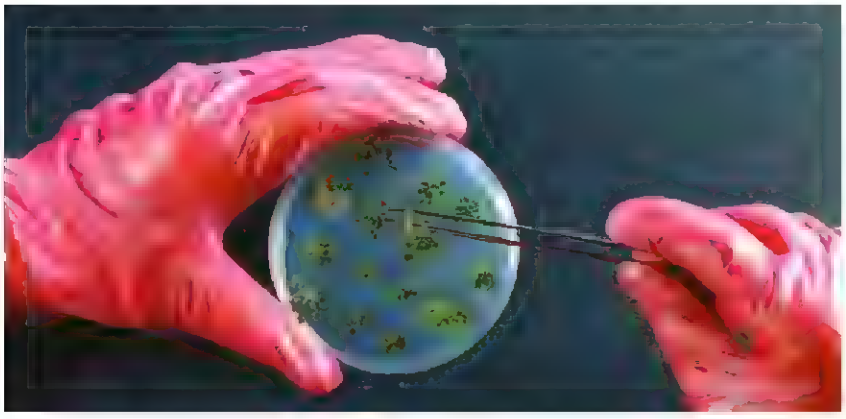

Figure 11 These newly formed shoots are clones, produced from the stem of a single plant. They will next be transferred onto a culture medium that will induce them to produce roots.

Through experiments using plant tissue culture, scientists have been able to show that it is usually the ratio of different plant growth regulators that determines the type of growth or differentiation that is induced. The ratios between cytokinins and auxins have been well described. A scientist can control the type of tissue produced by changing the ratio of these two plant growth regulators in the culture medium. If cytokinins are entirely absent in the medium, auxin causes the cells to just enlarge and they do not divide. If auxins are absent, cytokinins have no effect on cells. If cytokinin levels are high relative to auxins, the cells differentiate into shoots. But when auxin levels are high relative to cytokinins, the cells differentiate into roots.

Plant tissue culture was initially used exclusively for research on plant growth regulators and other compounds that might affect plants. Today, it has commercial applications. It is used to produce large quantities of identical individuals for breeding programs. The technique is especially useful for propagating tree species. It can take many years to produce tree species by natural means, and tissue culture can quickly produce many copies of an individual with desirable traits. Unfortunately, individuals produced in this way have no genetic diversity.

13.6 Summary

- Plant growth regulators are substances produced by the plant that regulate its growth and development.
- Changes in environmental factors can change the levels of plant growth regulator.
- The effect of any plant growth regulator depends on the tissue, the plant species, and the levels of other plant growth regulators.
- Auxins and gibberellins induce cell elongation in many tissues.
- Cytokinins induce cell division in many tissues.
- Ethylene regulates fruit ripening and stress responses in many plants.
- Abscisic acid inhibits growth and promotes dormancy in many species. It also induces the closing of stomata during water stress.

13.6 Questions

1. Name the five plant growth regulators that are found in most plants. K/U
2. Which plant growth regulators primarily promote cell elongation? Which primarily promote cell division? K/U
3. Describe how the Darwins were able to show that phototropisms in grasses are influenced by light reaching the growing tips of plants. K/U A
4. A growth response toward a stimulus is called a positive tropism, while a growth response away from a stimulus is called a negative tropism. Use these terms to describe the phototropisms and gravitropisms of roots and shoots. K/U K/U
5. How can an understanding of apical dominance be used to produce plants that have more lateral branches? In what way is this technique influencing the production of plant regulators within the plant? K/U A
6. Suggest a possible technique that might help achieve the following results: T/I A
   (a) produce grapes that are larger than normal
   (b) help plants survive while being shipped over long distances to garden centres
   (c) ensure that fruits do not become too ripe before they are ready to be sold in supermarkets
   (d) stimulate cells in tissue culture to produce roots
7. Nastic movements are an interesting type of plant response. They include the opening and closing of some flowers during the day and the sudden closing of a venus fly trap. Use the Internet and other sources to research and view video clips of nastic movements. T/I A
   (a) How do nastic movements differ from tropisms?
   (b) How are plants able to move tissues rapidly, as in the case of the venus fly trap?
   (c) How do the leaves of the Mimosa plant respond to touch?

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CHAPTER 13 Investigations

Investigation 13.2.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Methods of Asexual Reproduction

Asexual reproduction produces genetically identical copies (clones) of the parent plant. Commercial growers and everyday gardeners have found a number of methods to propagate desirable individual plants by inducing them to undergo asexual reproduction. In this investigation you will make cuttings from the leaves and stems of two different plant species and observe whether they can be induced to undergo asexual reproduction by producing roots.

Purpose

To observe the induction of asexual reproduction using plant cuttings

Experimental Design

Leaf and stem cuttings will be taken from each of two different plant species. The cuttings will be placed in water. The cuttings will be observed weekly for root formation.

Equipment and Materials

- single-edged razor blade
- two species of herbaceous plants (Species A and B)
- 4 small containers (for example, beakers, jars)
- water

Procedure

1. You will be observing two different types of cuttings from two plant species (A and B). Make a table to record your observations. Record the name of each species in your table.
2. Working with Species A, use the razor blade to cut one leaf petiole at a 45° angle, close to the stem.

Caution: Be careful using the razor blade. Make sure to handle it only by the non-sharp edge and to cut away from yourself and any person nearby.

3. Place the leaf cutting in a labelled container. Add water to the container until it is about 1 cm above the cut end.
4. Repeat Steps 2 and 3 for Species B.
5. Working with Species A, use the razor blade to take a stem cutting that contains the apical meristem and at least two leaves.
6. Place the stem cutting in a labelled container. Add water to the container until it is about 1 cm above the cut end. Remove any leaves that are below the surface of the water.
7. Place the containers with the cuttings under a lamp or in a sunny window.
8. Once a week, check each cutting for changes at the cut end. Make sure you add more water as needed. Record your observations, using either written descriptions or sketches, as appropriate.

Analyze and Evaluate

(a) Did the type of cutting (leaf or stem) affect the formation of roots? Was the effect the same for both plant species? Explain. T/I

(b) Suggest changes you could make to this procedure to better compare the differences in the rooting ability of the leaf and stem cuttings of the two species. T/I

(c) Identify any environmental variables that may have influenced the results and suggest how they might be controlled. T/I

Apply and Extend

(d) Design and write a procedure for an experiment to test whether the presence of light affects root formation in these plants.

(e) Suppose you owned a plant nursery. What would be the benefits and costs of using the procedure from this investigation in your business? Consider the time, labour, and economic costs and benefits in your answer. T/I A

(f) Asexual reproduction by grafting involves taking a very young branch of a woody plant from one individual and sealing it tightly to a cut stem or root of another individual. Eventually, the tissues from the two individuals grow together. Compare and contrast grafting to the procedure in this investigation. T/I C

Investigation 13.5.1 CONTROLLED EXPERIMENT

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Temperature, Light, and Seed Germination

Most seeds will not germinate unless certain environmental conditions exist. This helps to maximize the chances that the seedling will survive. In this investigation you will determine whether temperature and/or light affect the germination of radish seeds.

Testable Question

Will changes in temperature and/or light affect the germination of radish seeds?

Hypothesis/Prediction

Based on what you have learned about plant seeds, write a prediction that addresses the testable question.

Variables

Read the Procedure. Identify the independent (manipulated) variable(s) and the dependent (responding) variable(s).

Experimental Design

Radish seeds will be moistened and stored in sealed Petri dishes. The seeds will be kept at two different temperatures. Those kept at room temperature will be either exposed to normal daylight patterns or kept in total darkness. The number of germinated seeds will be counted every day for two weeks.

Equipment and Materials

- 3 Petri dishes
- paper towel cut to fit in Petri dishes
- masking tape
- waterproof marker
- refrigerator
- aluminum foil
- 30 radish seeds
- water

Procedure

1. Place paper towel in the bottom of each Petri dish so that it is flat against the bottom.
2. Add enough water to each Petri dish so that the paper towel is moist throughout but does not form a puddle on the surface. Pour off any excess.
3. Place 10 radish seeds on the moist paper towel in each Petri dish. The seeds should be spaced evenly apart (**Figure 1**).

Figure 1 Spread the seeds out so they are evenly spaced on the paper towel.

4. Place the top on each Petri dish. Run masking tape along the side of each dish to seal it.
5. With a marker, label the top of the three dishes A, B, and C.
6. Wrap dishes A and B in aluminum foil to keep out light. Place dish A in the refrigerator.
7. Place dishes B and C side by side near a window or other light source.
8. Each day, observe the seeds. Open the aluminum wrapping but do not open the Petri dishes. Record your observations. Count and record the total number of germinated seeds.
9. Repeat Step 8 once a day until there are no further changes in any of the dishes, or for two weeks.

Analyze and Evaluate

(a) Plot the number of germinated seeds per day on a graph. Plot the data for all three Petri dishes on one graph. T/I A

(b) In which Petri dish did the seeds germinate most quickly? most slowly? T/I

(c) Did all 10 seeds germinate in each dish by the end of the experiment? If not, which dishes had ungerminated seeds? T/I

(d) Why were dishes B and C placed next to each other? T/I

(e) Was temperature the only factor that could have affected the seeds in dishes A and B? Explain. T/I

(f) Did your results support your prediction? If not, rewrite your prediction. T/I

Apply and Extend

(g) Based on the results of your investigation, suggest whether radish seeds should be planted in early or late spring, and if they should be planted on the soil surface or be buried. T/I A

(h) Briefly describe how you could determine if germination was affected by the level of moisture. T/I

Investigation 13.5.2 CONTROLLED EXPERIMENT

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Factors Affecting Plant Growth and Differentiation

Plants respond to their environment through changes in their growth and development. In this experiment you will choose an environmental factor and investigate its effect on the growth of Wisconsin Fast Plants. The life cycle of these plants is only 35 to 45 days. Many stages of growth and development of these flowering plants can be observed within two weeks.

Testable Question

Choose an environmental factor that is likely to vary in the environment in Ontario. Write a testable question regarding this factor and plant growth and development.

Hypothesis/Prediction

Write a prediction based on your Testable Question, in a statement in the form "If . . . , then . . . ."

Variables

List the independent (manipulated) variable, the dependent (responding) variable(s), and the controlled variables. The responding variable(s) should be quantifiable, such as number of leaves or plant height.

Experimental Design

In a single paragraph, describe the procedure you will use and how you will change and control variables in your investigation.

Equipment and Materials

- soilless planting mixture
- small containers, such as clean yogurt cups
- ruler
- magnifying glass
- water
- Wisconsin Fast Plant seeds
- other materials, as needed

Procedure

1. Write your procedure as a series of numbered steps. Your steps must be clear enough that someone else could follow them. Make sure you include any necessary safety precautions.
2. When your teacher has approved your procedure, carry out your investigation.

Analyze and Evaluate

(a) Use graphs, tables, and/or photographs to display and analyze your data. T/I C

(b) Was your prediction correct? If not, write a new statement that best describes the relationship between your independent and dependent variables. T/I

(c) Identify any sources of experimental error in your investigation. T/I

(d) Describe how you would modify your procedure to reduce experimental error, if you were able to repeat this investigation. T/I

Apply and Extend

(e) Suppose you had a garden that contained a plant that responded in the same way as the Wisconsin Fast Plant to the environmental factor you investigated. Describe how you might modify your garden to benefit the growth of this plant. T/I A

CHAPTER 13 SUMMARY

Summary Questions

1. Create a study guide based on the Key Concepts listed at the beginning of the chapter, on page 586. For each point, create three or four subpoints that provide further information, relevant examples, explanatory diagrams, or general equations.
2. Return to the Starting Points questions at the beginning of the chapter, on page 586. Answer these questions using what you have learned in this chapter. Compare your answers with those that you gave at the beginning of the chapter. How has your understanding changed? What new knowledge do you have?

Vocabulary

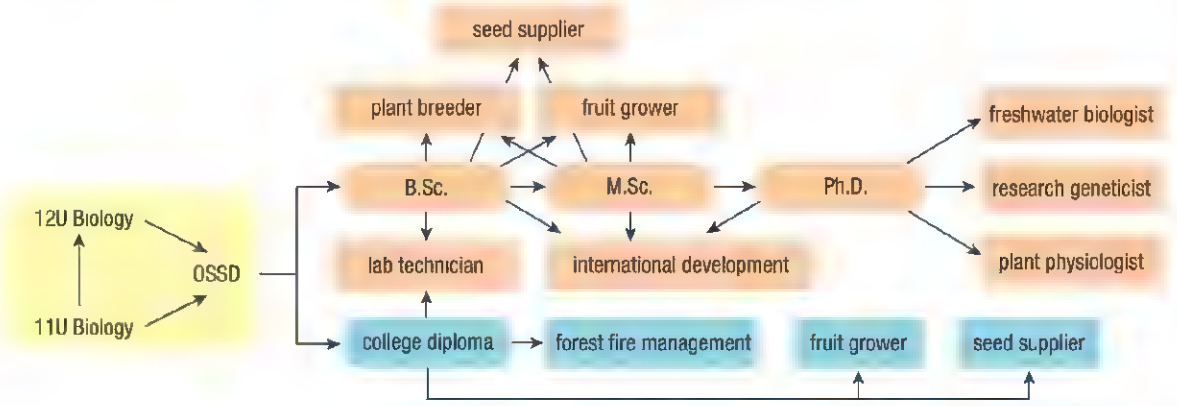
succession (p. 588)
primary succession (p. 588)
pioneer species (p. 588)
secondary succession (p. 590)
grafting (p. 594)
scion (p. 594)
stock (p. 594)
endosperm (p. 596)
pollination (p. 597)
pollen tube (p. 597)
stamen (p. 598)
anther (p. 598)
filament (p. 598)
carpel (p. 598)
stigma (p. 598)
style (p. 598)
cross-pollination (p. 600)
self-pollination (p. 600)
fruit (p. 600)
pericarp (p. 600)
growth (p. 605)
differentiation (p. 605)
apical meristem (p. 605)
primary growth (p. 605)
secondary growth (p. 605)
lateral meristem (cambium) (p 605)
photoreceptor (p. 608)
photoperiodism (p 608)
macronutrients (p. 609)
micronutrients (p. 610)
plant growth regulator (p. 613)
tropism (p 613)
phototropism (p. 613)
gravitropism (p 614)
thigmotropism (p 614)
apical dominance (p. 615)
senescence (p. 616)

CAREER PATHWAYS

Grade 11 Biology can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or postgraduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

SKILLS HANDBOOK A7

1. Select two careers related to plants that you find interesting. Research the educational pathways that you would need to follow to pursue these careers. What is involved in the required educational programs? Prepare a brief report of your findings.
2. For one of the two careers that you chose above, describe the career, main duties and responsibilities, working conditions, and setting. Also outline how the career benefits society and the environment.



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CHAPTER 13 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which of the following is most likely to be a site where primary succession occurs? (13.1) K/U
   (a) a snow-covered forest floor
   (b) a pristine wetland area
   (c) a newly hardened lava flow
   (d) none of the above
2. A population created by asexual reproduction
   (a) is genetically identical
   (b) is more vulnerable to disease-triggered extinction
   (c) may eventually reproduce sexually as well
   (d) all of the above (13.2) K/U
3. When a grower cuts a young branch from a plant that has desirable characteristics and attaches it to the stem of another plant, the grower is utilizing
   (a) grafting
   (b) stocking
   (c) secondary succession
   (d) mitosis (13.2) K/U
4. How do pollen grains get from a male cone to an ovule in a female cone? (13.3) K/U
   (a) pollination
   (b) asexual reproduction
   (c) mitosis
   (d) succession
5. Which part of the stamen produces pollen grains? (13.3) K/U
   (a) carpel
   (b) stigma
   (c) style
   (d) none of the above
6. Which of the following is the correct scientific term for any structure that is formed from a ripened ovary? (13.3) K/U
   (a) vegetable
   (b) fruit
   (c) pollinator
   (d) endosperm
7. All tissue formed from apical meristems is called
   (a) cambium tissue
   (b) lateral tissue
   (c) secondary tissue
   (d) primary tissue (13.5) K/U
8. Which of the following best defines thigmotropism? (13.6) K/U
   (a) a change in growth pattern in response to touch
   (b) a change in growth pattern in response to gravity
   (c) a change in growth pattern in response to light
   (d) a change in growth pattern in response to weather
9. Which of the following is true of abscisic acid (ABA)? (13.6) K/U
   (a) ABA levels decrease in response to changes in temperature and light, such as those that occur when seasons change.
   (b) The primary role of ABA is to inhibit growth.
   (c) Once ABA is applied to plants, the dormancy it induces cannot be reversed.
   (d) all of the above (13.6) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

10. Secondary succession occurs only in an area that has no plants, animals, or soil. (13.1) K/U
11. Planting species that are only one or two stages ahead in succession helps to ensure that the plants are in a community with biotic and abiotic factors that can support their growth and development. (13.1) K/U
12. All asexual reproduction in plants occurs by mitosis of diploid cells. (13.2) K/U
13. Grafting utilizes sexual reproduction. (13.2) K/U
14. No plant can reproduce both sexually and asexually. (13.3) K/U
15. Plants that are capable of self-pollination can also cross-pollinate. (13.3) K/U
16. Unlike most animals, most plants continue to grow in height for their entire life. (13.5) K/U
17. Secondary growth occurs in all plant species. (13.5) K/U
18. Gibberellins are a family of compounds that share a similar chemical structure and act in similar ways in plant cells. (13.6) K/U
19. Dormant plants are more vulnerable to damage than actively growing plants. (13.6) K/U

To do an online self-quiz,
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CHAPTER 13 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. The first species to colonize an area during succession is known as a
   (a) pioneer species
   (b) primary species
   (c) secondary species
   (d) succeeding species (13.1) K/U
2. What does asexual reproduction produce? (13.2) K/U
   (a) clones
   (b) genetically identical individuals
   (c) a guaranteed "passing down" of all traits
   (d) all of the above
3. Unlike asexual reproduction, sexual reproduction involves the union of two haploid cells that are produced through
   (a) succession
   (b) grafting
   (c) meiosis
   (d) mitosis (13.3) K/U
4. Which of these is the female reproductive floral part? (13.3) K/U
   (a) stamen
   (b) carpel
   (c) anther
   (d) filament
5. Wood is a product of
   (a) primary growth
   (b) secondary growth
   (c) self-pollination
   (d) mitosis (13.5) K/U
6. Which of the following is a macronutrient? (13.5) K/U
   (a) potassium
   (b) chlorine
   (c) copper
   (d) iron
7. Which of the following is one of the five plant growth regulators found in most plants? (13.6) K/U
   (a) auxins
   (b) cytokinins
   (c) abscisic acid
   (d) all of the above

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

8. The changes in the community that are happening on Mount St. Helens are a dramatic example of succession. (13.1) K/U
9. In plants, asexual reproduction is also called vegetative reproduction. (13.2) K/U
10. Plants that reproduce asexually must develop specialized reproductive structures, such as flowers or cones. (13.2) K/U
11. A seed has only two main functions: to protect and nourish the enclosed embryo. (13.3) K/U
12. There are eight micronutrients. (13.5) K/U
13. Growth is the process of cell specialization. (13.5) K/U
14. A tropism is a change in the direction of growth in response to a stimulus. (13.6) K/U

Match each item on the left with the most appropriate description on the right.

15.

(a) stamen	(i) supports anther
(b) carpel	(ii) male reproductive part of a flower
(c) anther	(iii) produces pollen
(d) stigma	(iv) leads to the ovary
(e) style	(v) female reproductive part of a flower
(f) filament	(vi) receives pollen grains

Write a short answer to each question.

16. Define primary succession. (13.1) K/U
17. List three abiotic factors that may change during succession. (13.1) K/U
18. List two examples you know of natural events that might lead to secondary succession. (13.1) K/U
19. What are suckers? (13.2) K/U
20. What is generally true of the strength or robustness of plantlets formed by asexual reproduction, compared to young seedlings formed by sexual reproduction? (13.2) K/U
21. What can be said about the genetic diversity of an apple orchard if most scions are from only a few individuals? (13.2) K/U
22. What are the two main dispersal methods of seeds? (13.3) K/U
23. What are microspores? (13.3) K/U

24. Name two fruits that are commonly referred to as vegetables. (13.3) K/U A
25. What is differentiation? (13.5) K/U
26. How does primary growth begin? (13.5) K/U
27. What will be different about a tree's growth ring that forms in a dry year from one that grows in a year with a lot of rain? (13.5) K/U
28. How are plants able to modify their growth and differentiation? (13.6) K/U
29. Define phototropism. (13.6) K/U
30. What does every cytokinin promote? (13.6) K/U

Understanding

31. What type of environment did the eruption of Mount St. Helens create? Explain which type of succession, if any, occurred. Why? (13.1) T/I
32. Give an example of a natural event that might lead to secondary succession. Describe what secondary succession might entail (species involved, growing patterns, and so on) following this event. (13.1) K/U
33. For the following biotic and abiotic factors, indicate whether each one increases or decreases as succession progresses. (13.1) K/U
    (a) plant diversity
    (b) exposed rock
    (c) available shelter
    (d) animal diversity
    (e) soil moisture
    (f) temperature at ground surface
34. Use **Figure 1** to answer the following questions. (13.1) K/U
    (a) What human activity most likely occurred?
    (b) Describe the process of secondary succession that might take place after such activity.

Figure 1

35. Succession eventually creates stable, diverse communities. Explain how traditional suburban yards may get in the way of succession. (13.1) K/U
36. Describe the process by which a plant reproduces asexually. What is one benefit to this type of reproduction? What is one drawback? (13.2) K/U
37. Early in history, people recognized that they could take advantage of plants' ability to reproduce asexually and use the various plant structures to their benefit. (13.2) K/U
    (a) What are benefits to humans of using some plants' ability to reproduce asexually?
    (b) List two farming techniques that use asexual reproduction in plants.
38. (a) What is grafting?
    (b) Give an example of how a grower might benefit by using grafting. (13.2) K/U
39. A single germinated grass seed has the ability to quickly give rise to a very large population. By what type of reproduction does this occur? Describe how the grass population is able to grow so quickly. (13.2) K/U
40. (a) What are the main functions of a seed?
    (b) Describe the structures seeds may have to help them carry out each of these functions. (13.3) K/U
41. (a) Identify one benefit of sexual reproduction.
    (b) Identify one drawback of sexual reproduction. (13.3) K/U
42. Describe the process of sexual reproduction in gymnosperms. You may wish to use diagrams to help in your description. (13.3) K/U C
43. Explain why fertilization in angiosperms is called double fertilization. You may wish to use diagrams to help in your explanation. (13.3) K/U C
44. Explain what a fruit is, and describe the process of fruit formation. (13.3) K/U
45. Recent disasters have motivated a push for faster development of alternative energy sources. One possible alternative to fossil fuels is biofuel. (13.4) K/U
    (a) What is biofuel?
    (b) Describe some of the positive and some of the negative aspects of the production and use of biofuels.
46. For each of the macronutrients phosphorus, calcium, and sulfur, describe the forms of the macronutrient that plants commonly absorb and the symptoms plants might show if they were deficient in that macronutrient. (13.5) K/U

47. (a) Identify the four main environmental factors that affect plant growth and development.
    (b) Choose one and explain how it affects plant growth and development. (13.5) K/U
48. Explain how each of the five plant growth regulators found in most plants acts to modify the growth and differentiation of plants. (13.6) K/U
49. Explain why a plant seedling grown in a sunny window bends toward the light. (13.6) K/U
50. What is the primary role of abscisic acid (ABA) in a plant? Why do ABA levels rise and what effect does this rise have on the plant? (13.6) K/U
51. Explain how plant growth regulators are used in plant tissue culture. What are the advantages of tissue culture? How is it being used? (13.6) K/U

Analysis and Application

52. Look at **Figure 2**. What type of succession do you think is likely to occur on this site? Why? Support your conclusion with facts you learned about succession. (13.1) T/I A

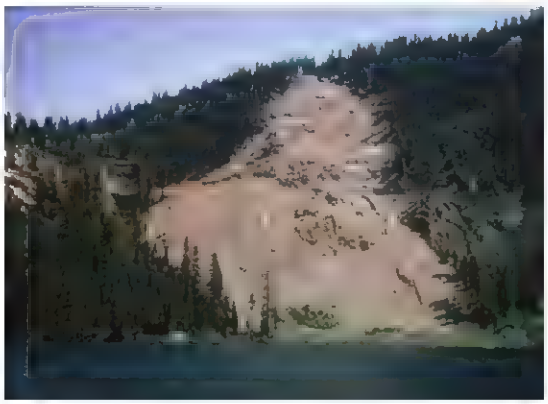

Figure 2

53. (a) Choose one human activity that adversely affects succession. Describe this activity and how it hinders biodiversity.
    (b) Using your knowledge of succession and biodiversity, solve the above problem by demonstrating how the human activity can be altered to lessen its negative effects on the surrounding ecosystem. (13.1) K/U A
54. Does the process of primary succession take longer in tropical or Arctic areas? Explain your reasoning. (13.1) K/U T/I A
55. You are a biologist who has been asked to increase biodiversity at a site that for many years has had very few plant species, most of those reproducing asexually. What are the first steps you would take in solving this problem? What types of plants would you introduce to this site? Present your answer in the form of a proposal to the landowners who hired you. (13.1) T/I C A
56. Dune grass is the dominant species along the edge of a certain beach. Inland, the ecosystem is predominantly mixed deciduous/coniferous forest. Predict what the area that is covered in grass will look like in 100 years. Assume the area is left undeveloped. Explain your predictions. (13.2) T/I A
57. Compare and contrast sexual and asexual reproduction in plants. (13.2, 13.3) K/U A
    (a) What are the advantages and disadvantages to each type of reproduction?
    (b) Describe two different environments, one in which asexual reproduction is more favourable and one in which sexual reproduction is more favourable.
58. Examine the flower in **Figure 3**. Is this flower a monocot or a eudicot? Explain your answer. (13.3) K/U A

Figure 3

59. As an orchard owner, you have discovered that there are certain varieties of apple tree that thrive in your orchard and certain varieties that do very poorly, yielding relatively few apples per tree. What steps might you take to maximize the apple yield from your orchard? Include specific examples and details about your plan in your answer. (13.3) C A

60. An apple tree seedling on an Ontario farm grew into an apple tree that eventually produced the popular McIntosh variety of apple. The tree died in 1906. Seeds from this tree produced other popular apple varieties including the Macoun, Spartan, Empire, and Cortland. (13.2, 13.3) K/U A
    (a) Explain how we continue to have large supplies of McIntosh apples even though the apple tree died long ago.
    (b) Apple trees cannot self-pollinate. Explain why the seeds from the McIntosh tree did not produce McIntosh apples.
61. (a) Hypothesize as to how a lack of a resource such as water or sunlight might affect a plant that usually reproduces asexually.
    (b) Give an example of a plant that can do this. (13.3) K/U T/I A
62. Seeds are a necessary part of sexual and asexual reproduction. (13.3) T/I A
    (a) What is the role of seeds in each of these very different types of reproduction?
    (b) What role does seed dispersal play in each of these types of reproduction?
63. Look at **Figure 4**. Based on what you can see, suggest the type of pollination method this plant species relies on. Support your answer. (13.3) K/U T/I

Figure 4

64. Some fruits, such as peppers, squash, tomatoes, and peas, are commonly called vegetables. Explain why this is incorrect. (13.3) K/U
65. How does the walking palm tree utilize growth and differentiation to help it survive? (13.5) K/U A
66. If an oak tree grown in Florida were transplanted to Ontario, would its leaves change colour at the same time as Ontario oak tree leaves? Explain why or why not. (13.5)
67. Compare and contrast primary growth with secondary growth. How are these two types of plant growth different? What distinguishes one from the other? Do all plants have both of these types of growth? Explain. (13.5) K/U
68. (a) Why is light so important to plant growth and development?
    (b) In what ways does the amount or intensity of light change over time for plants? Give examples of ways plants respond to changes in light. (13.5) K/U
69. Carbon, hydrogen, and oxygen are essential macronutrients for plants. However, no fertilizer lists these elements on the package. Explain why this is so. (13.5) K/U A
70. Suppose a classmate tells you that micronutrients are less important to plants than macronutrients because micronutrients are needed in smaller amounts. Do you think this is true? If not, how would you correct your classmate's idea? (13.5) K/U A
71. If you started your own plant nursery, explain two ways in which you could use different plant hormones to your advantage. (13.6) K/U A
72. An experimenter wanted to investigate the direction of seedling growth under two different conditions. In one seedling, the experimenter completely separated the tip from the shoot by inserting a thin slice of gelatin. He repeated the procedure on another seedling, except he used a thin sheet of glass to separate the tip from the shoot. An untouched seedling acted as a control. All three seedlings were lit from the side. Several days later, the control and the seedling with the gelatin insert had bent toward the light. The seedling with the glass insert still grew straight upward.(13.6) K/U T/I A
    (a) Interpret the experimental results.
    (b) For the seedlings that changed their direction of growth, which plant growth regulator do you think was responsible for the change in direction of growth? Explain.
73. Based on what you learned about ethylene, design a "super" ethylene that can induce major changes in various plant species. Pick a single plant species, and describe how your "super" ethylene would allow that species to survive any environmental changes. Formulate this growth regulator to be powerful enough to overcome any environmental adversity. Explain how your plant species would be able to survive virtually anything. Be creative, but use facts from your readings. (13.6) T/I C A

74. Suppose you are given a seed that has been treated with a substance that inhibits gravitropism. If the seed were planted, predict what would happen to the emerging roots and shoots. Explain your predictions. (13.6) K/U T/I A

75. A vine grows sideways, twisting along a railing. What type of tropism is the plant exhibiting? (13.6) K/U A

76. If you want full, bushy plants, which part of the plant would you trim to control auxin production? (13.6) K/U A

77. Four o'clock flowers bloom late in the day, as their name suggests. The flowers stay open all night and close the following morning. What type of response do these flowers demonstrate? (13.6) K/U A

78. Look at the two bunches of Thompson seedless grapes in **Figure 5**. One bunch is from an untreated vine and the other is from a treated vine. (13.6) K/U T/I A
    (a) Which growth regulator was applied to the treated vine? Explain your answer.
    (b) Explain the action of the regulator on the fruit.

Figure 5

Evaluation

79. Devise an environment that is ready for primary succession. Describe your environment in detail. What does it look like? Is it the result of some recent event, or has it remained unchanged for thousands of years? What will the pioneer species be, and how will this species create suitable conditions for other species and, eventually, an entire ecosystem? Be creative in your response. (13.1) T/I A

80. Some people feel that after a forest has been clear-cut, secondary succession should be allowed to happen by itself, and no new seedlings should be planted. Do you think this is a good idea? Why or why not? (13.1) T/I A

81. Based on what you know about asexual reproduction, invent an ecosystem in which only asexual reproduction exists. What would be different about this ecosystem from virtually any real ecosystem you can think of? What would the advantages be to this ecosystem and the different plant species that exist within it? What would be the disadvantages? Is this ecosystem feasible in the real world? Why or why not? (13.2) K/U T/I A

82. According to the fossil record, seed plants date back to 360 million years ago, when Earth's climate was becoming hotter and drier. What role did this global climate change likely play in the evolution of seed plants? (13.1, 13.2) K/U A

83. Suppose an ecosystem exists in which no winds ever blow and no animals exist. Devise a way or ways for various plant seeds to be dispersed within this ecosystem. How will plants be able to survive and increase their populations without the benefit of wind or animals to disperse their seeds? Be creative in the solutions you provide in your answer. (13.3) K/U T/I A

84 Predict what the world would be like if the use of biofuels replaced the use of fossil fuels almost completely. What would be different? Why? What might remain the same? What problems or issues that we face today might be lessened or eliminated if we relied more on biofuels? What new problems or issues might arise? (13.4) T/I C A

85. Based on what you know about plant growth and development and plant growth regulators, hypothesize as to how plants living in the extreme northern or extreme southern hemispheres adapt to the extreme changes in day length throughout the year. (13.5, 13.6) T/I A

Reflect on Your Learning

86. What aspect of succession did you find most interesting? Explain. K/U C

87. Knowing what you now know about how plants reproduce asexually, has your view of plants changed in any way? Why or why not? K/U C

88. Did you know that grafting was such a common method for reproducing plants asexually? What about this process do you find most interesting? Can you think of any examples of grafting in your nearby community? K/U C

89. Are there any aspects of sexual reproduction in plants that surprised you? Explain why or why not. K/U C

90. Do you think the products of plant asexual reproduction or the products of plant sexual reproduction are more important to society? Explain. K/U C

91. What was the most interesting thing you learned about plant growth and development and plant growth regulators? Explain why. K/U C

92. Aside from food and medicine, in what ways are plants used in your life? K/U C

Research

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93. In a bid to make housing from sustainable sources, some people are making houses out of straw. Research the use of straw bales as a building material. What is straw? What are its advantages and disadvantages as a building material? How might increasing the demand for straw-bale housing materials affect Canadian farmers? How might an increase in straw-bale housing affect the sustainability of other natural resources? Summarize your findings and create a straw-bale housing fact sheet. T/I C A

94. "Good things grow in Ontario" is a slogan the Ontario government uses to encourage consumers to buy locally grown fruits and vegetables. Consumers are becoming aware of the benefits of buying produce that is grown locally, and farmers markets are becoming increasingly popular. Research the local food movement in Ontario and create a one page summary of how the local food movement benefits communities. T/I C A

95. Research the variety of adaptations different plant species have for dispersing their seeds by wind, animals, and water. Draw diagrams to show how these adaptations help disperse the seeds. T/I C A

96. Cereals are crops that are grown for their seeds; they include wheat, barley, rice, oats, and corn. What cereals are grown most commonly in Canada? In Ontario? Are they all grown for human consumption? Based on your findings, evaluate the importance of these crops to Canadian society. T/I C A

97. Research the plant breeder Luther Burbank. What were his major contributions to fruit and vegetable breeding? Write a report on your findings. Present your report to your classmates. T/I C A

98. Some scientists think that certain species of green algae should be in the kingdom Plantae. Conduct research to explain what reasons these scientists might use to defend their position. K/U T/I A

99. Use the Internet and other sources to research tropical plant species that have fruits with air cavities that allow them to float. How might natural selection have led to this adaptation? K/U T/I A

UNIT 5 UNIT TASK

Plants That Changed the World

Throughout this unit you have discovered some of the many ways that society has been, and continues to be, affected by plants. You have also learned a great deal about how society uses plants. One of the most important lessons we must learn as a society is how to use plants in a sustainable way, making sure we weigh their roles in maintaining our environment against our need for plant products (**Figure 1**). We also have to maintain biodiversity, which will ensure our environment is in the best possible position to adapt to challenges such as climate change.

Figure 1 (a) Slash-and-burn agriculture and (b) industrial agriculture. Which do you think is more sustainable?

In this Unit Task you will explore the relationship between one plant species and human society. To meet this challenge you will choose one plant species and research its production and use in societies, including Canadian societies. You will also research the historical production and use of the species in Canada and elsewhere. You will then analyze your research and evaluate the importance of the plant to the growth and development of these societies. You will also evaluate which, if any, of these societies grow and use this plant today in an environmentally sustainable way.

Your task has five different components.

1. Plant Biology

- Conduct research on the natural history of your chosen plant species (**Figure 2**). Find out about its size, appearance, and growth patterns; the environmental factors in its habitat; and where it occurs naturally.
- Record your research findings, using illustrations, maps, and diagrams where appropriate.

Figure 2 Some of the plants that have had a profound effect on humans

2. Plant Product(s)

- Identify the useful product(s) that are associated with this plant.
- Determine the physical and/or chemical properties of the plant product that contribute to its usefulness. If possible, obtain a sample of the product and evaluate these properties directly. For example, if your plant produces food, determine the nutrients in the food; if your plant produces fibre, determine the flexibility of the fibre.

3. Role in Human Society

- Conduct additional research to find out the history of the use of this plant in Canada and worldwide. Choose a method that best conveys your findings. For example, a timeline might be useful.
- Describe the impact of this product on the economy, the environment, and the quality of human life.

- Evaluate the importance of this product to the growth and development of human society. Support your evaluation with quantitative data, where possible.

4. Technology and Research

- Outline the technologies that are used to grow and reproduce the plant and to manufacture the product. Use graphics such as flowcharts and illustrations as much as possible.
- Conduct a cost–benefit analysis of the economic, social, and environmental impacts associated with this plant product.
- Describe any research that is being carried out to reduce any negative effects associated with this plant product.

5. Career Connections

- Identify and list at least two careers associated with the technologies you included in Part 4.
- Choose one career from your list. Research the educational requirements needed to enter this career. Be as specific as possible.

Conclusion

Based on your research and analysis, explain why the following statements do or do not describe your species:

- This plant product has had a significant impact on the growth and development of human society.
- The properties and value of this product can be explained through an understanding of plant biology.
- Sustaining the use of this plant product in the long term depends on the application of technologies that support ecosystems and maintain plant diversity.

ASSESSMENT CHECKLIST

Your completed Performance Task will be assessed according to the following criteria:

Knowledge/Understanding

- ✓ Demonstrate a knowledge of how plants respond and adapt to their environment.
- ✓ Demonstrate an understanding of the relationship between plant diversity and sustainability.

Thinking/Investigation

- ✓ Ask questions and plan research to answer these questions using a variety of sources.
- ✓ Identify issues related to the role of a plant in supporting and developing human society.
- ✓ Analyze and evaluate information, and develop informed views based on this evaluation.

Communication

- ✓ Communicate your findings in an organized and creative manner, using visual and written methods.

Application

- ✓ Demonstrate application of knowledge of plant biology and sustainability in evaluating a plant use.
- ✓ Connect issues of human needs and environmental factors to changes in human society and ecosystems.

UNIT 5 SELF-QUIZ

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

For each question, select the best answer from the four alternatives.

1. Which type of plant tissue contains non-specialized cells? (12.1) K/U
   (a) dermal tissue
   (b) vascular tissue
   (c) ground tissue
   (d) meristematic tissue
2. Which two plant groups do humans most rely on for food, fibre, and building materials? (12.1) K/U
   (a) monocots and eudicots
   (b) pteridophytes and lycophytes
   (c) gymnosperms and lycophytes
   (d) monocots and pteridophytes
3. Which portion of a leaf helps prevent water loss and forms a barrier against bacteria and insects? (12.2) K/U
   (a) aerenchyma
   (b) mesophyll
   (c) cuticle
   (d) lower epidermis
4. What are the two main functions of leaves? (12.2) K/U
   (a) sugar transport and starch storage
   (b) photosynthesis and gas exchange
   (c) reproduction and support
   (d) water and nutrient absorption
5. Which of the following would you expect to find in water lily leaves but not in most terrestrial leaves? (12.2) K/U
   (a) xylem
   (b) mesophyll
   (c) aerenchyma
   (d) guard cells
6. A plant with a woody stem
   (a) is neither a gymnosperm nor an angiosperm
   (b) might be either a gymnosperm or an angiosperm
   (c) is an angiosperm, not a gymnosperm
   (d) is a gymnosperm, not an angiosperm (12.3) K/U
7. Which of these is not a part of tree bark? (12.3) K/U
   (a) phloem
   (b) cork cambium
   (c) xylem
   (d) cork
8. What are the main functions of the cells in the root cortex? (12.4) K/U
   (a) storing carbohydrates and transporting water
   (b) providing a protective covering for the meristem
   (c) making and storing glucose
   (d) producing new cells to increase the length of the root
9. What is contained in the vascular cylinder of plant roots? (12.4) K/U
   (a) the root hairs and the root cap
   (b) the xylem and the phloem
   (c) the Casparian strip and the root cortex
   (d) the endodermis and root hairs
10. For which process is transpiration most critical? (12.5) K/U
    (a) the movement of xylem sap to the tops of trees
    (b) the movement of sugars from a source to a sink
    (c) the movement of nutrients into the plant roots
    (d) the movement of xylem sap from the root to the stem
11. A solar water pump applies the concept of transpiration to meet human needs. It is an example of
    (a) biomimicry
    (b) cell specialization
    (c) capillary action
    (d) transpiration (12.6) K/U
12. Which is an example of primary succession? (13.1) K/U
    (a) a pioneer species colonizing a newly formed island
    (b) wildflowers growing in an abandoned farm field
    (c) tree seedlings growing after a forest fire
    (d) dandelions appearing in a suburban yard
13. Which of the following is a benefit of asexual reproduction of plants? (13.2) K/U
    (a) genetic diversity among offspring
    (b) production of seeds
    (c) formation of robust plantlets
    (d) production of beautiful flowers
14. Gymnosperm pollination happens by means of
    (a) wind
    (b) birds
    (c) water
    (d) bees (13.3) K/U
15. In what structures is gymnosperm pollen produced? (13.3) K/U
    (a) flowers
    (b) cones
    (c) seeds
    (d) fruit
16. Which is a male reproductive structure of an angiosperm plant? (13.3) K/U
    (a) anther
    (b) stigma
    (c) style
    (d) carpel

17. Which of the following groups of plants have photosynthetic gametophytes and swimming sperm? (13.3) K/U
    (a) ferns and conifers
    (b) mosses and flowering plants
    (c) conifers and flowering plants
    (d) mosses and ferns
18. Which is an example of a biofuel? (13.4) K/U
    (a) natural gas
    (b) coal
    (c) oil
    (d) plant materials
19. In a shoot, where do tissues start to form? (13.5) K/U
    (a) apical meristem
    (b) zone of elongation
    (c) zone of differentiation
    (d) zone of maturation
20. What is the source of secondary growth in plants? (13.5) K/U
    (a) apical meristem
    (b) root cap
    (c) lateral meristem
    (d) primary tissue
21. Which is a micronutrient needed by plants? (13.5) K/U
    (a) water
    (b) nitrogen
    (c) copper
    (d) light
22. Which of the following is NOT a role of soil in plant growth? (13.5) K/U
    (a) providing support for the plant
    (b) supplying the water that the plant needs
    (c) supplying glucose to the plant roots
    (d) providing the roots with air
23. Which substance inhibits plant growth? (13.6) K/U
    (a) cytokinin
    (b) gibberellin
    (c) ethylene
    (d) abscisic acid
24. Which of the following stimulates cell division in meristems? (13.6) K/U
    (a) auxin
    (b) cytokinin
    (c) ethylene
    (d) gibberellin

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

25. A plant's stem and leaves are parts of its shoot system. (12.1) K/U
26. Xylem and phloem are types of plant vascular tissues. (12.1) K/U
27. Two key advances found in gymnosperms are seeds and fruits. (12.1) K/U
28. The products of photosynthesis are glucose and water. (12.1) K/U
29. Leaves with branching veins are found on monocots. (12.2) K/U
30. Openings in the epidermis of leaves, through which gas is exchanged, are called stomata. (12.2) K/U
31. Asparagus is an example of a plant that has a woody stem. (12.3) K/U
32. In herbaceous monocot stems, the vascular bundles are arranged in a circle. (12.3) K/U
33. The functioning of tracheids is controlled by the activity of companion cells. (12.3) K/U
34. The primary function of the Casparian strip is to keep water and nutrients from escaping from the vascular cylinder. (12.4) K/U
35. In a taproot system the main root grows straight down. (12.4) K/U
36. The relationship between plant roots and mycorrhizal fungi is mutualistic. (12.4) K/U
37. Most soil nutrients enter root hairs by the process of osmosis. (12.5) K/U
38. Any plant cell that stores or uses sugars is called a source. (12.5) K/U
39. The loss of trees associated with the development of cities results in urban heat islands. (12.7) K/U
40. Change in an existing community of organisms following a disturbance is called secondary succession. (13.1) K/U
41. As succession progresses, the diversity of species usually decreases. (13.1) K/U
42. The term "vegetative reproduction" is used to describe sexual reproduction in plants. (13.2) K/U
43. The petals and stamens of monocot flowers always occur in multiples of five. (13.3) K/U
44. Walnuts and peas are examples of fruits. (13.3) K/U
45. Biofuels are resources that are classified as non-renewable resources. (13.4) K/U
46. The process by which a cell becomes specialized is called differentiation. (13.5) K/U
47. Photoperiodism is a plant's response to changing day length. (13.5) K/U
48. Thigmotropism is a plant's response to gravity. (13.6) K/U

To do an online self-quiz, GO TO NELSON SCIENCE

UNIT 5 REVIEW

K/U Knowledge/Understanding T/I Thinking/Investigation C Communication A Application

Knowledge

For each question, select the best answer from the four alternatives.

1. Which of these is produced during photosynthesis? (12.1) K/U
   (a) solar energy
   (b) carbon dioxide
   (c) glucose
   (d) water
2. Sclerenchyma, collenchyma, and parenchyma are all classified as
   (a) ground tissues
   (b) vascular tissues
   (c) dermal tissues
   (d) meristematic tissues (12.1) K/U
3. What type of substance is chlorophyll? (12.2) K/U
   (a) a sugar
   (b) a starch
   (c) a photopigment
   (d) a tannin
4. In which type of plant is aerenchyma most likely to be found? (12.2) K/U
   (a) those that live in hot climates
   (b) those that live in the Arctic
   (c) those that live in very dry places
   (d) those that live in water
5. The cuticle from certain plant leaves is often used to make which of the following products? (12.2) K/U
   (a) teas
   (b) medicines
   (c) waxes and polishes
   (d) dyes
6. Which best describes the role that stems play in plant reproduction? (12.3) K/U
   (a) Stems are the site of sex cell production.
   (b) Stems protect the plant seeds.
   (c) Stems position cones and flowers in positions ideal for pollination.
   (d) Stems contain substances that attract pollinators.
7. Woody stems are made up primarily of
   (a) phloem
   (b) xylem
   (c) the root cap
   (d) the Casparian strip (12.3) K/U
8. What is the primary site or sites of sugar transport in plants? (12.5) K/U
   (a) phloem
   (b) Casparian strip
   (c) xylem
   (d) both xylem and phloem
9. Why do plant populations become established more quickly during secondary succession than during primary succession? (13.1) K/U
   (a) Soil is already present during secondary succession.
   (b) Animals eat more plants during primary succession.
   (c) Water must form before primary succession can occur.
   (d) Sunlight is not available during primary succession.
10. Rhizomes are plant structures involved in
    (a) sexual reproduction
    (b) photosynthesis
    (c) production of fruit
    (d) asexual reproduction (13.2) K/U
11. Grafting is a technique used to induce a type of
    (a) sexual reproduction that occurs naturally
    (b) sexual reproduction that does not occur naturally
    (c) asexual reproduction that occurs naturally
    (d) asexual reproduction that does not occur naturally (13.2) K/U
12. When does fruit development begin? (13.3) K/U
    (a) when a seed is formed
    (b) when pollen is released
    (c) when an ovule is fertilized
    (d) when the pollen tube begins to grow
13. Which component of soil is the source of many of the nutrients needed by plants? (13.5) K/U
    (a) sand
    (b) air
    (c) clay
    (d) humus
14. Which of the following is responsible for leaf drop? (13.6) K/U
    (a) gibberellins
    (b) cytokinins
    (c) ethylene
    (d) abscisic acid

Match each term on the left with the most appropriate description on the right.

15. (a) cuticle (i) a layer of loosely packed cells that allow for gas exchange
    (b) upper epidermis (ii) waxy, protective coating
    (c) guard cells (iii) control the opening and closing of stomata
    (d) spongy mesophyll (iv) made up of transparent cells that allow light to pass through
    (e) palisade mesophyll (v) made up of elongated cells with many chloroplasts (12.2) K/U
16. (a) auxin (i) promotes cell division
    (b) cytokinin (ii) promotes cell elongation
    (c) ethylene (iii) inhibits growth
    (d) abscisic acid (iv) protects a plant against environmental stress (13.6) K/U

Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true.

17. The major function of dermal tissue is protection. (12.1) K/U
18. The flat part of a leaf is called the petiole. (12.2) K/U
19. In woody stems, new xylem and phloem are formed by the vascular cambium. (12.3) K/U
20. A root system with many small roots is called a taproot system. (12.4) K/U
21. Water enters plant roots by the process of active transport. (12.5) K/U
22. Using natural materials as an inspiration for technological design is called biomimicry. (12.6) K/U
23. The construction of cities usually causes the number of trees in an area to increase. (12.7) K/U
24. A stable community developed through succession does not respond to environmental changes. (13.1) K/U
25. In an apple tree that has formed by grafting, the plant that provides the stem and root system is called the stock. (13.2) K/U
26. The function of the endosperm is to provide nutrition for the plant embryo. (13.3) K/U
27. Most biofuels are produced from the cellulose in plant cell walls. (13.4) K/U
28. In woody plants, growth rings are found in both stems and roots. (13.5) K/U

Write a short answer to each question.

29. Define the term "carbohydrate." (12.1) K/U
30. List three ways that plants avoid being eaten by herbivores. (12.1) K/U
31. List two plant structures that are parts of the shoot system. (12.1) K/U
32. Describe the function of a petiole. (12.2) K/U
33. Explain how the function of cacti spines differs from the function of most leaves. (12.2) K/U
34. Define the term "vascular bundle." (12 3) K/U
35. List three types of phloem cells found in vascular plants. (12.3) K/U
36. Identify three types of underground stems. (12.3) K/U
37. What are the two parts of a root tip? (12.4) K/U
38. Identify three roots that humans eat. (12.4) K/U
39. Compare xerophytes and hydrophytes and include examples of their special adaptations. (12.2, 12.3, 12.4) K/U T/I A
40. What type of transport moves substances from an area of low concentration to an area of high concentration? (12.5) K/U
41. Define the term "root pressure." (12.5) K/U
42. Explain what is meant by the terms "source" and "sink." How does this relate to sugar production and storage in plants? (12.5) K/U A
43. What process in plants was the inspiration for a solar-powered water pump design? (12.6) K/U
44. Give two examples of events that would lead to primary succession occurring in an area. (13.1) K/U
45. New potato plants can grow from the "eyes" on potatoes. Is this classified as sexual reproduction or asexual reproduction? (13.2) K/U
46. Identify one cost and one benefit of asexual reproduction in plants. (13.2) K/U
47. Identify one cost and one benefit of sexual reproduction in plants. (13.3) K/U
48. List two reasons why dispersal of seeds is important. (13.3) K/U
49. Define the term "megaspore." (13.3) K/U
50. Identify two parts of a stamen. (13.3) K/U
51. Why is it not surprising that seeds are among the most nutritious parts of any plant? (13.2, 13.3) K/U T/I
52. Describe five benefits of urban gardens. (13.1, 13.3) K/U A
53. Describe one possible disadvantage of the use of biofuels. (13.4) K/U
54. What aspect of a plant's size is increased by secondary growth? (13.5) K/U
55. Identify two macronutrients that plants obtain from atmospheric gases. (13.5) K/U
56. Define "plant growth regulator." (13.6) K/U

Understanding

57. Explain how the pitcher plant in **Figure 1** is adapted to the environmental conditions in which it lives. (12.1) K/U

Figure 1

58. Write a sentence that summarizes the process of photosynthesis. (12.1) K/U
59. Draw a diagram that shows the generalized structure of a vascular plant. Label the following: stem, leaf, root hairs, root tips, root system, shoot system. (12.1) K/U
60. List the groups into which dicot plants can be classified. (12.1) K/U
61. Compare the structure and functions of the leaves of a jade plant to those of the leaves of a maple tree. (12.2) K/U
62. (a) What are the general effects that psychotropic chemicals have on animals?
    (b) Name two psychotropic chemicals produced by plants
    (c) Explain how production of psychotropic chemicals benefits plants. (12.2) K/U
63. Compare and contrast the stems of cacti and baobab trees. Identify one way they are adapted that is similar and one way that is different. (12.3) K/U T/I
64. (a) Describe the differences in spring wood and summer wood.
    (b) Explain how these differences affect the appearance of growth rings. (12.3) K/U T/I
65. Provide an example for the following uses of plant stems. (12.3) K/U
    (a) fuel
    (b) food
    (c) textiles
    (d) dyes
    (e) other chemicals
    (f) medicines
66. Describe the structure of a root hair and explain how its structure helps it carry out its function. (12.4) K/U
67. Some plants, such as beans, have a mutualistic relationship with nitrogen-fixing bacteria.
    (a) How does the plant benefit from the relationship?
    (b) How do the bacteria benefit from the relationship? (12.4) K/U
68. (a) Define "capillary action."
    (b) How does changing the diameter of a tube affect capillary action? (12.5) K/U T/I
69. Compare and contrast sugar transport and water transport in a plant. (12.5) K/U
    (a) Identify the direction or directions in which water and sugars are transported within the plant.
    (b) Identify the processes involved in the transport of each substance.
    (c) Identify the type of vascular tissue primarily used in the transport of each substance.
70. Explain how information about the process of transpiration can be applied to make an affordable water purification system. (12.6) K/U
71. What type of succession is depicted in **Figure 2**? Describe the role these organisms play in soil formation. (13.1)

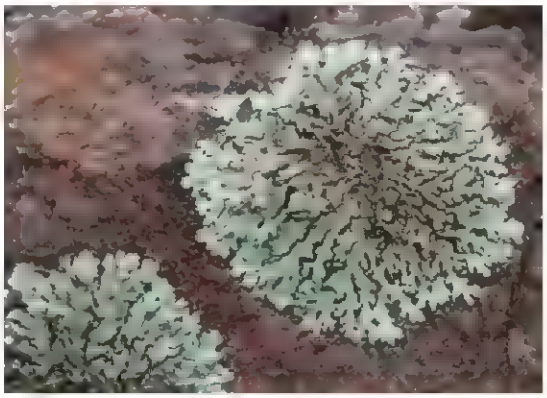


Figure 2

72. (a) Identify two ways that primary succession and secondary succession are similar.
    (b) Identify two ways that primary succession and secondary succession are different. (13.1) K/U
73. Describe one way in which human activities can encourage succession. Explain. (13.1) K/U
74. (a) Identify one advantage of using grafting on fruit trees.
    (b) Identify one disadvantage of producing an entire orchard of fruit trees using grafts from a single plant. (13.2) K/U

75. Summarize the functions of each of the following structures. (13.3) K/U T/I
    (a) seeds
    (b) fruits
    (c) flowers
76. How are cross pollination and self pollination different? How are they similar? (13.3) K/U T/I
77. (a) Explain why many commercial fruit producers grow plants in monoculture, even though it reduces biodiversity.
    (b) How does the commercial production of fruit in greenhouses affect the use of resources?
    (c) What are two ways that individual consumers can make fruit production more sustainable? (13.3) K/U
78. Explain the role of the following three processes in primary growth. (13.5) K/U
    (a) cell division
    (b) cell elongation
    (c) cell differentiation
79. (a) Define the term "photoperiodism."
    (b) Describe an example of photoperiodism.
    (c) Explain how photoperiodism benefits plants. (13.5) K/U
80. Identify a plant process for which each of the following macronutrients is used. (13.5) K/U
    (a) oxygen
    (b) carbon
    (c) sulfur
81. Compare and contrast phototropism and photoperiodism. Identify one way that they are similar and one way that they are different. (13.6) K/U
82. (a) Explain how auxins can be used as a herbicide.
    (b) Explain how auxins can help commercial fruit growers reduce the cost of harvesting fruit. (13.6) K/U

Analysis and Application

83. The law of conservation of energy states that energy cannot be created or destroyed, but it can change form. (12.1) T/I A
    (a) Apply this information to explain why the statement "plants make their own energy" is not correct.
    (b) Correctly state what happens to energy during the process of photosynthesis.
84. Water is sometimes called the "universal solvent" because of its ability to dissolve many substances. Describe two specific ways that this property of water is vital to plants. (12.1, 12.5) T/I A
85. Gas exchange is required for photosynthesis. (12.2) K/U A
    (a) Identify the gas that plants must take in to perform photosynthesis.
    (b) Identify the gases that are released due to photosynthesis.
86. Plant pathologists study plant diseases. Imagine a plant pathologist is examining a sample of a plant leaf that was submitted to his laboratory. (12.2) T/I A
    (a) The pathologist first examined the cuticle of the leaf. What are the characteristics of the cuticle that the pathologist would expect to see, if the plant were healthy?
    (b) The pathologist then examined the epidermal cells of the leaf. What are the characteristics of epidermal cells that the pathologist would expect to see, if the plant were healthy?
    (c) The pathologist found that both the cuticle and the epidermal cells had become opaque, due to environmental conditions. How would this affect the function of the leaf?
    (d) How would this condition affect the plant as a whole?
87. Examine the leaf shown in **Figure 3**. Does it come from a eudicot or a monocot? Explain. (12.2) T/I A

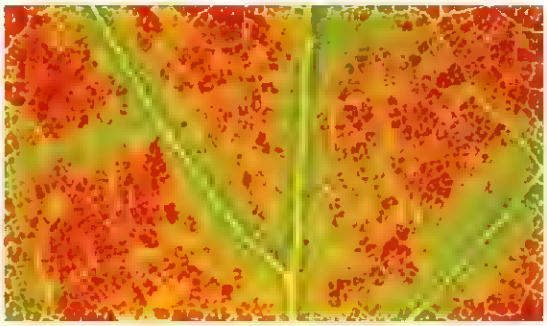


Figure 3

88. Pine needles and cactus spines are both types of leaves that show significant adaptations to environmental conditions. (12.2) T/I A
    (a) Identify the environmental conditions to which each of these adaptations is related.
    (b) Identify one way that these leaves are similar in structure.
    (c) Identify two ways that the specializations of these leaves differ.

89. The cuticle is a waxy layer produced by cells of the epidermis. Design an experiment to test the role of the upper and lower leaf cuticles in retaining water. Assume that you have a solvent that allows you to remove the cuticle without otherwise harming the plant. Your design should include
    (a) a testable question
    (b) a hypothesis
    (c) a list of variables—controlled, manipulated, and responding
    (d) a step-by-step procedure (12.2) T/I A

90. Sieve plates and perforation plates are found in the cells of vascular tissue. (12 3) K/U
    (a) Identify one way that they are similar in structure.
    (b) Identify the type of vascular tissue in which each is found.
    (c) Compare and contrast the functions of these structures.

91. Explain why you would never find a cactus with a woody stem. (12.3) A

92. Most plants use starches to store chemical energy within roots and seeds and use sugars in their fruits and nectar. Suggest a reason why most plants do not store large amounts of sugars in their roots or use starch in fruits and nectar. (12.4)

93. Copy **Table 1** into your notebook and use it to help plan a menu for a meal. Fill in the table; then write out your complete menu. Your menu must include one food from each of these categories, and can include other foods as well. (12.2, 12.3, 12.4, 13.3) A

Table 1

Category	Food
root	
stem	
leaf	
seed (not enclosed in a fruit)	
fruit	

94. Write a short paragraph explaining the following statement: the entry of water into a plant depends upon the exit of water from the plant. (12.5) K/U A

95. Describe what you would expect to happen to the root pressure within the vascular bundle in the following situations if the Casparian strip were suddenly damaged. (12.5) K/U T/I A
    (a) The root cells are actively transporting nutrients into the vascular bundle and water is following by osmosis.
    (b) The plants are exposed to high temperatures and the surrounding soil is very dry.

96. How does an understanding of transpiration account for the fact that roof-top gardens reduce summer cooling costs? (12.5) K/U A

97. (a) Make a flow chart to summarize the three main stages of sugar transport in vascular plants.
    (b) Identify the mechanism (passive transport or active transport) used in each of the three stages in the flowchart.
    (c) Write a paragraph that uses the information in the flowchart, your responses to (b), and the following list of terms to summarize sugar transport from a mesophyll cell to a root cell:
    - source
    - sink
    - xylem
    - phloem
    - companion cell
    - sieve tube elements (12.5) K/U C

98. In an example of biomimicry, the characteristics of the surface of water lily leaves are used to help make solar panels that stay clean. Think of and describe another way that the characteristics of the surface of water lily leaves could be applied. (12.6) T/I A

99. Given the amount of time that living things have been on Earth, why has succession not resulted in stable communities in every ecosystem on Earth? (13.1) K/U A

100. In 1883, a massive volcanic eruption buried the Indonesian island of Krakatau and the surrounding islands in ash to a depth of over 30 m. All plant and animal life was wiped out. By 1934, more than 270 plant species had returned to Krakatau.
    (a) Is this an example of primary or secondary succession? Explain why.
    (b) Propose two ways in which plants might have reached these uninhabited Pacific islands.
    (c) Hypothesize what the pattern of animal recolonization might have been. What types of animals may have arrived first? Explain why some of these could survive while others probably could not. (13.1) T/I A

101. Many people maintain grass lawns around their homes. Comment on the biological diversity of a grass lawn from the perspective of ecological succession. What successional stage does a lawn represent? How many different plant species are present? (13.1) T/I A

102. How are asexual and sexual reproduction important to the process of succession? (13.1, 13.2, 13.3) T/I A

103. Suppose your neighbour weeds his lawn regularly, but the dandelions keep reappearing. Explain why this is happening and suggest what your neighbour should do to stop the dandelions from regrowing. (13.2) K/U A

104. Apply what you know about asexual reproduction to explain why is it important that commercial growers carefully control the abiotic and biotic factors in commercial nurseries. (13.2) T/I A

105. The seeds of just three grasses—rice, wheat, and corn—supply humans with well over half of our entire food supply. Thus, humans' ecological niche could be labelled "grass-seed eaters." Brainstorm some of the advantages of using seeds as a major food source rather than using animals or other plant parts. Consider nutrient content, availability, and storage. (13.3) K/U A
    (a) Explain how human uses of seeds and fruits shaped human culture in the past.
    (b) Describe how modern commercial production of fruits and seeds is important to today's society.
    (c) Use what you have learned about the positive and negative effects of commercial production of seeds and fruits to predict how the industry might change in the next 20 years. Support your prediction with information from the unit. (13.3) T/I A

106. Imagine that several years ago your class took part in a tree-planting activity. The trees your class planted in several locations in the schoolyard have grown and changed over time. (13.5) T/I A
    (a) Describe how primary growth changed the trees your class planted.
    (b) From what region of the plant did the primary growth originate?
    (c) Describe how secondary growth changed the trees your class planted.
    (d) From what regions of the plant did the secondary growth originate?
    (e) One of the trees has grown far less than the others that were planted at the same time, although it is of the same species. What are two factors that might have caused this difference?

107. Climate change can affect plant life in several ways. (13.1, 13.5) T/I A
    (a) Explain how a global increase in temperatures can affect plant species that rely on temperature cues to time their flowering.
    (b) Explain how species of plants that do not rely on temperature cues to time their flowering can be affected by the changed flowering date of the plants that are influenced by climate change.
    (c) Global climate change can also vary the timing of the migration of insects and animals. How could this affect plant species?
    (d) Use your answers from (a), (b), and (c) to explain how global climate change can result in secondary succession in an ecosystem.

108. Imagine you have been asked to develop a soil mixture in which to grow houseplants. You have been given clay, sand, and humus as ingredients for your soil mixtures. You develop three different mixtures. Each has different amounts of each ingredient. The mixtures are labelled A, B, and C. You place a plant in each mixture and observe its growth over time. (13.5) T/I A
    (a) The plant in soil mixture A shows stunted growth and chlorosis. Which of the three soil ingredients is not present in great enough quantity?
    (b) The plant in soil mixture B loses turgor and wilts. You notice that water flows though the soil mixture very quickly. Which soil ingredient is probably present in too great a proportion in mixture B?
    (c) Water puddles on the surface of soil mixture C. The plant's roots and the base of its stem show signs of mould. Which soil ingredient is probably present in too great a proportion in mixture C?

109. The seeds of many northern plant species will not germinate until they have been exposed to a period of sub-zero temperatures. Suggest a possible reason for this adaptation. (13.5) A

110. A home gardener has several bushes that are growing tall and thin. They get enough sunlight, water and nutrients. Suggest how the gardener can make these plants grow bushier without applying any chemicals. Explain how your course of action would affect the plant. (13.6) A

Evaluation

111. Carbon dioxide is a greenhouse gas, a type of gas that helps Earth's atmosphere stay in a temperature range that allows life. Use this information to explain the role that plants have in regulating Earth's climate. Then evaluate the idea that global warming can be counteracted by increasing the number of plants on Earth. Explain the scientific reasoning behind this idea. (12.1) T/I C A

112. Evaluate the following statement: humans could live without other animals but could not live without plants. Do you think this statement is true or false? Give several reasons to support your conclusion. (12.1) T/I C A

113. In a bid to increase efficiency, suppose a logging company has removed all the trees from an area, including those along creek banks. Water erosion has since increased. The company has offered to line these creek banks with rocks to prevent further erosion. Evaluate this plan and decide if it is a good idea. If you do not support this idea, propose another way to prevent erosion and explain why it is better than the company's plan. (12.4) T/I A

114. Researchers are investigating plants with high photosynthetic rates as sources of biofuel. (13.4) T/I A
    (a) Use what you know about photosynthesis to explain why the photosynthetic rate of a particular plant affects its usefulness for biofuel.
    (b) Brainstorm a list of three other attributes you think would be important for a plant that was used to generate biofuels. Explain each of your choices.

115. "Don't reinvent the wheel" means using knowledge or information that already exists to solve a problem, rather than trying to solve a problem starting from scratch. Explain how biomimicry can be used to help people avoid reinventing the wheel. (12.6) A

116. Do you think city planners should be required to include trees in their plans for cities? State at least two specific reasons to support your response. (12.7) K/U A

117. Suppose a homeowner decides to allow succession to occur in her yard. Some of her neighbours do not approve of this. Write a short letter to a local newspaper justifying her decision and addressing the neighbours' concerns. (13.1) T/I A C

118. Some substances produced by plants can be used in harmful ways by humans. For example, the nicotine in tobacco leaves is part of cigarettes and other tobacco products that harm human health. Imagine that a group of concerned individuals has proposed eradicating all plants that produce substances that can be used in harmful ways by humans. Do you think this is a reasonable solution? Explain why or why not. (12.2) T/I C A

119. Suppose someone tells you that the mechanism of phototropism is that cytokinins stimulate cells on the shaded side of the stem to produce more cells. As a result of these additional cells, the stem bends toward the light. Modify this explanation to correct any misconceptions. (13.6) A

120. Almost all bananas consumed in Canada and the United States are of the Cavendish variety. How might choosing to eat a variety of bananas promote sustainable agriculture and biodiversity? (13.3) K/U A

Reflect on Your Learning

121. Identify and describe one specific way that the information in this unit changed your perception of the importance of plants to human life. C A

122. You have read about different ways that fruit production can be made more sustainable. Is there anything you could do or are there changes you could make in your daily life to help make fruit production more sustainable? Explain. C A

123. Many people's idea of an ideal park is paved walking paths and perfectly manicured grass. From what you have learned in this chapter, has your perception of an ideal park changed at all? Explain why or why not. C A

124. Plant growth regulation is an active field of research. If you were a researcher, which plant growth regulator would you want to find out more about, and why? C A

Research

GO TO NELSON SCIENCE

125. Research to learn more about dendrochronology, or the study of tree rings. Find out about the information that can be learned by examining tree rings and learn more about ways this information can be applied in different fields, such as ecology and archaeology. Then draw a cross-section of a tree. Make tree rings for a series of at least 15 years. Be sure the tree rings show some variation. Show your diagram to other students in the class, and describe ecological factors that caused the variations in the tree rings. Write a short summary that explains how the information in the tree rings you drew could be applied by researchers in another field. T/I C A

126. A number of varieties of apples are grown for human consumption. Research the development of the McIntosh apple. Find out more about the development of this variety and how grafting is used to produce apples of consistent characteristics. Find out why a seed from a McIntosh apple will not produce a tree that bears McIntosh apples. Make a brochure about McIntosh apples to share what you have learned T/I C A

127. When genetically modified food crops are planted, they can end up cross-pollinating non-modified forms of the same plant species. Research to learn more about the problems caused by cross-pollination of genetically modified crops and wild crops, and learn what steps have been taken to prevent this from occurring. Share what you have learned in a newspaper-style article. T/I C A

128. Learn more about "heirloom" varieties of fruits and vegetables. In recent years these varieties have become more popular. Find out what makes a particular variety an heirloom and how planting and consuming heirloom varieties of fruits and vegetables has an ecological benefit. Make a print advertisement for heirloom varieties of fruits and vegetables that incorporates what you have learned. T/I C A

129. Research phytoremediation. Find out what it is and what its benefits and drawbacks are. Identify plant species that are commonly used in bioremediation and explain what each does. In what sort of situations can bioremediation be used? How is it being applied to fish-farming operations? T/I A

130. Find out more about the role that forest fires play in the reproduction and growth of plants. Find specific examples of plant species that require fire for a stage in reproduction. Also, find out how growth in a different species is affected after a fire when the amount of sunlight reaching a forest floor changes. Write a short report to share what you learn. T/I C A

131. Carry out research to learn how climate change affects plant life in Canada. Prepare a script for a 3 min radio broadcast that could be used to share what you learn. T/I C A

132. Find out more about the year 1816, sometimes called "the year without a summer." Learn how the unusual weather conditions of this year affected plants, especially crops grown for food. Work in a group of four students to share a presentation that includes specific information about the impact of these unusual weather conditions on plant life. T/I C A

133. Cut flowers are beautiful, but they last only a short time in water. Use what you have learned in this chapter and do additional research to determine why cut flowers do not last long. Find out more about the preservative packets that are often packaged with cut flowers. Use what you learn to make a care instruction tag that could be included with cut flowers to let other people know how to make their cut flowers last as long as possible. T/I C A

134. Research the practice of crop rotation. Find out how this practice is used to promote plant growth. Relate what you learn to information found in the chapter about the needs of plants. Discuss what you learn with three other students. Then, with your group, share two interesting facts about crop rotation with the class. T/I C A

135. Long-day and short-day plants require specific lighting conditions in order to flower. Do online research to learn how knowledge of such lighting conditions is used by growers to produce flowers at a particular time of year, such as poinsettias at Christmas. T/I

136. Scientists have developed genetically engineered tomato plants that produce very low quantities of ethylene. The fruits of these plants mature but are unable to ripen. Once the fruits are picked, they can be stored for weeks at a time. The fruits will then ripen quickly if they are exposed to ethylene gas. If this technique were applied to many food plants it could reduce the amount food lost to overripening. Suggest possible benefits and risks of this technology. Do online research to find out if these engineered tomatoes are currently being sold. K/U A

Appendices

CONTENTS

Appendix A Skills Handbook 643

A1 Safety.....643
- **A1.1** Safety Conventions and Symbols.....643
- **A1.2** Safety in the Laboratory 645

A2 Scientific Inquiry.....648
- **A2.1** Skills of Scientific Inquiry.....648
- **A2.2** Controlled Experiments 649
- **A2.3** Correlational Studies.....650
- **A2.4** Observational Studies 651
- **A2.5** Field Studies 652
- **A2.6** Lab Reports.....652

A3 Laboratory Skills and Techniques.....654
- **A3.1** Dissection 654
- **A3.2** Biological Drawings.....654
- **A3.3** Care and Use of the Microscope 655
- **A3.4** Preparing Slides and Staining Techniques .657
- **A3.5** Using the Stethoscope and Sphygmomanometer 658

A4 Scientific Publications 659

A5 Exploring Issues and Applications 660
- **A5.1** Research Skills 660
- **A5.2** Risk–Benefit Analysis Model 661

A6 Math Skills 662
- **A6.1** Scientific Notation 662
- **A6.2** Uncertainty in Measurements 662
- **A6.3** Probability.....664
- **A6.4** Graphs 665

A7 Choosing Appropriate Career Pathways 667

Appendix B Reference.....668

SI Base Units 668
Some SI-Derived Units. 668
Numerical Prefixes 668
The Greek Alphabet 669
Data for Some Radioisotopes 669
Methods of Cell Membrane Transport 670
Periodic Table of the Elements 672

Appendix C Answers 674

SKILLS HANDBOOK LINKS

Throughout this textbook you will see links to the Skills Handbook where appropriate. These links tell you that there is supporting material in the Skills Handbook that will help you with that activity

APPENDIX A SKILLS HANDBOOK

A1 Safety

A1.1 Safety Conventions and Symbols

Although we make every effort to make the science experience a safe one, there are some inherent risks. These risks are generally associated with the materials and equipment used, and with disregard of safety instructions when conducting investigations. Most of these risks pose no more danger than we normally experience in everyday life. We can reduce these risks by being aware of the possible hazards, knowing the rules, behaving appropriately, and using common sense.

You share the responsibility not only for your own safety, but also for the safety of those around you (**Figure 1**). Always alert your teacher in case of an accident. In this textbook, chemicals, equipment, and procedures that are hazardous are indicated by the appropriate Workplace Hazardous Materials Information System (WHMIS) symbol or by .

Figure 1 Taking the proper safety precautions will ensure a safe environment for you and your classmates.

WHMIS SYMBOLS AND HHPS

The Workplace Hazardous Materials Information System (WHMIS) provides workers and students with complete and accurate information about hazardous products. All chemical products supplied to schools, businesses, and industries must contain standardized labels and be accompanied by a Material Safety Data Sheet (MSDS). The MSDS provides detailed information about the product. Clear and standardized symbols are an important component of WHMIS (**Table 1**, p. 644). These symbols must be present on the product's original container and shown on other containers if the product is transferred.

The *Canadian Hazardous Products Act* requires manufacturers of consumer products containing chemicals to include a symbol that specifies the nature of the hazard and whether it is the container or the contents that are dangerous. In addition, the label must state any secondary hazards, first-aid treatment, storage, and disposal. Household Hazardous Product Symbols (HHPS) are used to show the type of hazard. The shape of the frame around the symbol indicates whether the hazard is due to the contents or the container (**Figure 2**).

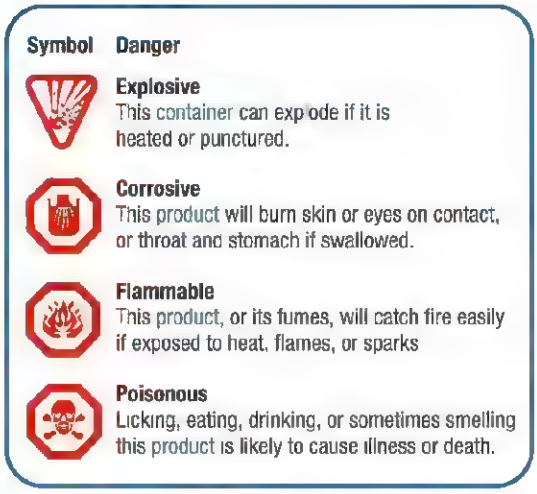


Figure 2 Household Hazardous Products Symbols (HHPS) appear on many products. A triangular frame indicates that the container is potentially dangerous. An octagonal frame indicates that the contents pose a hazard.

Table 1 The Workplace Hazardous Materials Information System (WHMIS)

Class and type of compounds	WHMIS symbol	Risks	Precautions
Class A: *Compressed Gas* Material that is normally gaseous and kept in a pressurized container		• could explode due to pressure • could explode if heated or dropped • possible hazard from both the force of exp osion and the release of contents	• ensure container is always secured • store in designated areas • do not drop or allow to fall
Class B: *Flammable and Combustible Materials* Materials that wil continue to burn after being exposed to a flame or other ignition source		• may ign te spontaneously • may release flammable products if allowed to degrade or when exposed to water	• store in designated areas • work in well-ventilated areas • avoid heating • avoid sparks and flames • ensure that electrical sources are safe
Class C: *Oxidizing Materials* Materials that can cause other materials to burn or support combustion		• can cause skin or eye burns • increase f re and explosion hazards • may cause combustibles to explode or react violently	• store away from combustibles • wear body, hand, face, and eye protection • store in container that will not rust or oxid ze
Class D: *Toxic Materials Immediate and Severe* Poisons and potentially fata materials that cause immediate and severe harm		• may be fatal if ingested or inhaled • may be absorbed through the skin • small volumes have a toxic effect	• avoid breathing dust or vapours • avoid contact with skin or eyes • wear protective clothing, and face and eye protection • work in well-ventilated areas and wear breathing protection
Class D: *Toxic Materials Long Term Concealed* Materials that have a harmful effect after repeated exposures or over a long period		• may cause death or permanent injury • may cause birth defects or sterility • may cause cancer • may be sensitizers causing allergies	• wear appropriate personal protection • work in well ventilated areas • store in appropriate designated areas • avoid direct contact • use hand, body, face, and eye protection • ensure respiratory and body protection is appropr ate for the specific hazard
Class D: *Biohazardous Infectious Materials* Infectious agents or a biologica toxin causing a serious disease or death		• may cause anaphylactic shock • includes viruses, yeasts, moulds, bacteria, and parasites that affect humans • includes fluids containing toxic products • includes cellular components	• special training is required to hand e materials • work in designated biological areas with appropriate engineering controls • avoid forming aerosols • avoid breathing vapours • avoid contamination of people and/or area • store in special designated areas
Class E: *Corrosive Materials* Materials that react w th metals and living tissue		• eye and skin irritation on exposure • severe burns/tissue damage on longer exposure • lung damage if inhaled • may cause blindness if contacts eyes • environmental damage from fumes	• wear body, hand, face, and eye protection • use breathing apparatus • ensure protective equipment is appropriate • work in a well-ventilated area • avoid all direct body contact • use appropriate storage containers and ensure non-venting closures
Class F: *Dangerously Reactive Materials* Materials that may have unexpected react ons		• may react with water • may be chemically unstable • may explode if exposed to shock or heat • may release toxic or flammable vapours • may vigorously polymerize • may burn unexpectedly	• handle with care, avoiding vibration shocks, and sudden temperature changes • store in appropriate containers • ensure storage containers are sealed • store and work in designated areas

A1.2 Safety in the Laboratory

Safety in the laboratory is an attitude and a habit more than it is a set of rules. It is easier to prevent accidents than to deal with the consequences of an accident. Most of the following rules are common sense:

- Do not enter a laboratory unless a teacher or other supervisor is present, or you have permission to do so.
- Know your school's safety regulations.
- Tell your teacher about any allergies or medical problems you may have.
- Wear eye protection, a lab apron, and safety gloves when instructed by your teacher. Wear closed shoes.
- Tie back long hair and wear a protective lab coat over loose clothing. Remove any loose jewellery and finger rings.
- Keep yourself and your work area tidy and clean.
- Never eat, drink, or chew gum in the laboratory.
- Know the location of MSDS information, exits, and all safety equipment, such as the first-aid kit, fire blanket, fire extinguisher, and eyewash station, and be familiar with their contents and operation.
- Avoid moving suddenly or rapidly in the laboratory, especially near chemicals or sharp instruments.
- Never change anything, or start an activity or investigation on your own, without your teacher's approval. Before you start an investigation that you have designed yourself, get your teacher's approval.
- Never work in a crowded area or alone in the laboratory.
- Always wear approved eye protection in a laboratory. Keep the safety glasses or goggles over your eyes, not on top of your head. For certain experiments, full face protection may be necessary.
- If you must wear contact lenses in the laboratory, be extra careful; whether or not you wear contact lenses, do not touch your eyes without first washing your hands. If you do wear contact lenses, make sure that your teacher is aware of it. Carry your lens case and a pair of glasses with you.
- If you wear prescription eyeglasses, you must still wear the appropriate eye protection on top of them.
- Always stand up when doing laboratory practical work. Do not sit down.
- Wash your hands with soap and warm water when you finish an investigation, and before you leave the laboratory.
- Never use a mouthpiece that has been in another student's mouth. Always disinfect any equipment that is going in your mouth before you use it.
- Use stands, clamps, and holders to secure any potentially dangerous or fragile equipment that could be tipped over.
- Do not taste any substance in a laboratory.
- Never smell chemicals unless specifically instructed to do so by your teacher. Do not inhale the vapours, or gas, directly from the container.
- Report all accidents.
- Inform your teacher of any spills and follow your teacher's instructions on how to clean up the spill. Clean up all spills, even water spills, immediately.

HANDLING GLASSWARE SAFELY

- Never use glassware that is broken, cracked, or chipped. Give such glassware to your teacher or dispose of it as directed. Do not put the item back into circulation.
- Never pick up broken glassware with your fingers. Use a broom and dustpan.
- Check with your teacher before heating any glassware. Heat glassware only if it is approved for heating.
- Be very careful when cleaning glassware. There is an increased risk of breakage from dropping when the glassware is wet and slippery.
- If you cut yourself, inform your teacher immediately and get appropriate first aid.

USING SHARP INSTRUMENTS SAFELY

- Make sure that your instruments are sharp. Dull cutting instruments require more pressure than sharp instruments and are more likely to slip.
- Always transport a scalpel in a dissection case or box. Never carry the scalpel from one area of the laboratory to another with an exposed blade.
- Always cut away from yourself and others.
- If you cut yourself, inform your teacher immediately and get appropriate first aid.

HEAT SAFETY

- Make sure that heating equipment, such as the burner, hot plate, or electric heater, is secure on the bench and clamped in place when necessary.
- Do not use a laboratory burner near wooden shelves, flammable liquids, or any other item that is combustible.

- Do not allow overheating if you are performing an experiment in a closed area.
- Always assume that hot plates and electric heaters are hot and use protective gloves when handling.
- Do not touch a light source that has been on for some time. It may be hot and can cause burns.
- Where burners or hot plates are being used, never pick up a glass object without first checking the temperature by placing your hand near but not touching it. Glass and metal items that have been heated may not appear to be hot, but can cause burns.
- Never look down the barrel of a laboratory burner.
- Always pick up a burner by its base, never by its barrel.
- Never leave a lighted burner unattended.
- Any metal powder can be explosive. Do not put these in a flame.
- When heating a test tube over a laboratory burner, use a test tube holder and spurt cap. Holding the test tube at an angle, with the open end pointed away from you and others, gently move the test tube back and forth through the flame.
- To heat a beaker, put it on the hot plate and secure with a ring support attached to a utility stand. (Placing a wire gauze under the beaker is optional.)
- Remember to include a cooling time in your experiment plan; do not put away hot equipment.

FIRE SAFETY

To use a burner:

- Tie back long hair and tie back or roll up long sleeves or other loose clothing.
- Secure the burner to a stand using a metal clamp.
- Check that the rubber hose is properly connected to the gas valve.
- Close the air vents on the burner. Use a sparker to light the burner.
- Open the air vents just enough to get a blue flame.
- Control the size of the flame using the gas valve.
- Immediately inform your teacher of any fires. A very small fire in a container may be extinguished by covering the container with a wet paper towel or a ceramic square to cut off the supply of air. Alternatively, sand may be used to smother small fires. A bucket of sand with a scoop should be available in the laboratory.
- Different extinguishers are effective for different classes of fires. The fire classes are outlined in **Table 2**. Fire extinguishers in the laboratory are 2A10BC. They extinguish class A, B, and C fires.

Table 2 Classes of Fires

Class	Description	Firefighting strategy
Class A	• ordinary combustible materials that leave coals or ashes (for example, wood, paper, cloth)	• water or dry chemical extinguishers
Class B	• flammable liquids (for example, gasoline or solvents)	• carbon dioxide or dry chemical extinguishers • do not use water
Class C	• live electrical equipment (for example, appliances, photocopiers, computers, laboratory equipment)	• carbon dioxide or dry chemical extinguishers • do not use water
Class D	• burning metals (for example, sodium, potassium, magnesium, aluminum)	• sand, salt, or graphite • do not use water
Class E	• radioactive substance	• requires special consideration at each site

- If anyone's clothes or hair catch fire, tell the person to drop to the floor and roll. Then use a fire blanket to smother the flames. Never wrap the blanket around a standing person on fire.
- For larger fires, immediately evacuate the area. Call the office or sound the fire alarm. Do not try to extinguish larger fires. As you leave the classroom, make sure that the windows and doors are closed.
- If you use a fire extinguisher, direct the extinguisher at the base of the fire and use a sweeping motion, moving the extinguisher nozzle back and forth across the front of the fire's base.

ELECTRICAL SAFETY

- Do not operate electrical equipment near running water or a large container of water. Water or wet hands should never be near electrical equipment such as a hot plate, a light source, or a microscope.
- Check the condition of electrical equipment. Do not use it if wires or plugs are damaged, or if the ground pin has been removed.
- If using a light source, check that the wires of the light fixture are not frayed, and that the bulb socket is in good shape and well secured to a stand.
- Make sure that electrical cords are not placed where someone could trip over them.

- When unplugging equipment, remove the plug gently from the socket. Do not pull on the cord.
- When using variable power supplies, start at low voltage and increase slowly.

HANDLING ANIMALS, PLANTS, AND OTHER ORGANISMS SAFELY

- Ensure that your teacher is aware of any plant or animal allergies that you may have.
- Never bring a plant, animal, or other organism to school without receiving prior permission from your teacher.
- Wear gloves and wash your hands before and after feeding or handling an animal, touching materials from the animal's cage or tank, or handling bacterial cultures.
- Do not grow any micro-organisms other than those that occur naturally on mouldy bread, cheese, and mildewed objects. Anaerobic bacteria should not be grown.
- Cultures should be grown at room temperature or in the range of 25 °C to 32 °C. Incubation at 37 °C may encourage the growth of micro-organisms that are capable of living in the human body.
- Bacteria from soils should not be grown because of the possibility of culturing tetanus-causing organisms.
- Spores collected from household locations, such as telephones or bathrooms, should not be cultured in the laboratory. The body can destroy small numbers of these bacteria, but may not be able to cope with large numbers.
- Remains of plants and animals can generally be disposed of in school garbage containers. Fungi and bacterial cultures should be autoclaved or treated with a fungicide or antibacterial soap before disposal.
- All surfaces and equipment used in culturing micro-organisms should be washed with a disinfectant (for example, a solution of bleach).
- Apparatuses used in microbiology should be autoclaved because liquid disinfectants and germicidal agents generally cannot guarantee complete sterilization.
- Wild or sick animals should never be brought into the lab. Dead animals, wild or tame, that have died from unknown causes should also not be brought into the lab
- Preserved specimens should be removed from the preservative with gloves or tongs and rinsed thoroughly in running water.
- Before going on field trips, become familiar with any dangerous plants and animals that may be common in the area (for example, poison ivy, poisonous snakes).
- Notify your teacher of any medical conditions or allergies that you have that could be affected as a result of exposure to any plants or animals on the field trip.

WASTE DISPOSAL

Waste disposal at school, at home, and at work is a societal issue. Most laboratory waste can be washed down the drain or, if it is in solid form, placed in ordinary garbage containers. However, some waste must be treated more carefully. It is your responsibility to follow procedures and to dispose of waste in the safest possible manner according to your teacher's instructions.

FIRST AID

The following guidelines apply in case of an injury, such as a burn, cut, chemical spill, ingestion, inhalation, or splash in the eyes:

- Always inform your teacher immediately of any injury.
- If the injury is a minor cut or abrasion, wash the area thoroughly. Using a compress (for example, clean paper towels), apply pressure to the cut to stop the bleeding. When bleeding has stopped, replace the compress with a sterile bandage. If the cut is serious, apply pressure and seek medical attention immediately.
- If you get a solution in your eye, quickly use the eyewash or nearest running water. Continue to rinse the eye with water for at least 15 min. Unless you have a plumbed eyewash system, you will also need assistance in refilling the eyewash container. Have another student inform your teacher of the accident. The injured eye should be examined by a doctor.
- If the injury is a burn, immediately immerse the affected area in cold water, or run cold water gently over the burned area. This will reduce the temperature and prevent further tissue damage.
- In case of electric shock, unplug the appliance and do not touch it or the victim. Inform your teacher immediately.
- If a classmate's injury has rendered him/her unconscious, notify your teacher immediately. Your teacher will perform CPR if necessary. Do not administer CPR unless under specific instructions from your teacher. Call the school office and request emergency medical help.

A2 Scientific Inquiry

In our attempts to further our understanding of the natural world, we encounter questions, mysteries, or events that are not readily explainable. To develop explanations, we investigate using scientific inquiry. An important aspect of scientific inquiry is that science is only one of many ways people explore, explain, and come to know the world around them. Scientific inquiry is a multifaceted process that involves the following: identifying questions that can be answered through scientific investigations; using appropriate tools and techniques to gather, analyze, and interpret data; developing descriptions, explanations, predictions, and models using evidence; thinking critically and logically to make the relationships between evidence and explanations; recognizing and analyzing alternative explanations and predictions; and communicating scientific procedures and explanations.

The methods used in scientific inquiry depend, to a large degree, on the purpose of the inquiry. There are four common types of scientific inquiry: (1) the controlled experiment, (2) the correlational study, (3) the observational study, and (4) the field study. These types of scientific inquiry require specific skills. The skills are discussed below, followed by a detailed description of how they relate to each of the four types of scientific inquiry.

A2.1 Skills of Scientific Inquiry

Scientific inquiry requires certain skills that are important in the process of conducting an investigation. These skills can be organized into four categories: initiating and planning, performing and recording, analyzing and interpreting, and communicating.

INITIATING AND PLANNING

(1) Questioning: Most scientific investigations begin with a question. It is important to ask the right questions. In certain types of scientific inquiry, the question must be testable. This means that it must ask about a possible cause-and-effect relationship. A cause-and-effect relationship is one in which a change in one variable (see #3) causes a change in another variable. A testable question might start in one of the following ways: What causes . . . ? How does . . . affect . . . ? If . . . , what happens to . . . ?

(2) Researching: This is a skill that occurs across all four categories of scientific inquiry and includes preparing for research, accessing resources, processing information, and transferring learning. The process involves identifying the type of information that is required, using strategies to locate and access the information, recording the information, synthesizing findings, and formulating conclusions.

(3) Identifying variables: Considering the variables involved in an investigation is an important step in designing an effective investigation.

Variables are any factors that could affect the outcome of an investigation. There are three kinds of variables in a controlled experiment: the manipulated variable, the responding variable, and the controlled variables.

- The manipulated variable (also known as the independent variable or cause variable) is the variable that is deliberately changed by the investigator.
- The responding variable (also known as the dependent variable or effect variable) is the variable that the investigator believes will be affected by a change in the manipulated variable.
- The controlled variables are variables that may affect the responding variable, but that are held constant so that they cannot affect the responding variable. A controlled experiment is a test of whether (and how) a manipulated variable affects a responding variable. To make the test fair, all other variables that may affect the responding variable are kept constant (unchanging).

(4) Hypothesizing: A hypothesis is a predicted answer to the testable question. It proposes a possible explanation based on an already known scientific theory, law, or other generalization.

A hypothesis may be written in the form of an "If . . . , then . . . because . . ." statement. If the manipulated (independent) variable is changed in a particular way, then we predict that the responding (dependent) variable will change in a particular way, and we provide a theoretical explanation for the prediction. You may create more than one hypothesis from the same testable question. For example,

"If an air-filled balloon is placed in a freezer and its temperature is decreased, then its volume will decrease because, according to the kinetic molecular theory, atoms and molecules slow down and occupy less space at lower temperatures."

When you conduct an investigation, your observations do not always support the prediction in your hypothesis. When this happens, you may re evaluate and modify your hypothesis and design a new experiment.

(5) Planning: Planning an inquiry activity involves developing an experimental design, identifying variables, selecting necessary equipment and materials, addressing safety concerns, and writing a step-by-step procedure.

PERFORMING AND RECORDING

(1) Conducting inquiry: As you perform an investigation, follow the steps in the procedure carefully and thoroughly. Check with your teacher if you find that you need to make significant alterations to your procedure. Use all equipment and materials safely, appropriately, and with precision.

(2) Making observations: When you conduct an investigation, you should make accurate observations at regular intervals and record them carefully and accurately. Record exactly what you observe. Observations from an experiment may not always be what you expect them to be. Qualitative (descriptive) and quantitative (measured) observations may be made during an investigation. Some observations may also be provided for you during an investigation.

Quantitative observations are based on measured quantities such as temperature, volume, and mass. They are usually recorded in data tables.

Qualitative observations describe characteristics that cannot be expressed in numbers, such as texture, smell, and taste. They can be recorded using words, pictures, tables, or labelled diagrams.

(3) Collecting, organizing, and recording data: During an investigation you should collect and record all data and observations, and organize these into formats that are easily interpreted (such as tables, charts, etc.).

ANALYZING AND INTERPRETING

(1) Analyzing: Analyzing involves looking for patterns and relationships that will help you explain your results and give you new information about the question you are investigating. Your analysis will tell you whether your observations support your hypothesis.

(2) Evaluating: It is very important to evaluate the evidence that is obtained through observations and analysis. When evaluating the results of an investigation, here are some aspects you should consider:

Experimental design: Were there any problems with the way you planned your experiment? Did you control all the variables except for the manipulated variable?

- Equipment and materials: Was the equipment adequate? Would other equipment have been better? Was something used incorrectly? Did you have difficulty with a piece of equipment?
- Skills: Did you have the appropriate skills for the investigation? Did you have to use a skill that you were just beginning to learn?
- Observations: Did you accurately record all the relevant observations?

COMMUNICATING

(1) It is important to share both your process and your results. Other people may want to repeat your investigation, or they may want to use or apply your results in another situation. Your write-up or report should reflect the process of scientific inquiry that you used in your investigation.

(2) At this stage, you should be prepared to extend insights and opinions from your findings, suggest areas for further investigation, and relate research findings to the world around you.

In the following sections, we will detail the components of the four types of investigation: controlled experiments, correlational studies, observational studies, and field studies.

A2.2 Controlled Experiments

A controlled experiment is an example of scientific inquiry in which a manipulated variable is intentionally changed to determine its effect on a responding variable. All other variables are controlled (kept constant). Controlled experiments are performed when the purpose of the inquiry is to create, test, or use a scientific concept.

The common components of controlled experiments are outlined below. Note that there are normally many cycles through the steps during an actual experiment.

TESTABLE QUESTION

A testable question forms the basis for your controlled experiment: the investigation is designed to answer the question. Controlled experiments are about relationships among variables, so your question could be about the effects on variable A when variable B is changed.

VARIABLES

You must identify all major variables that you will measure and/or control in your investigation. What is the manipulated (independent) variable? What is the responding (dependent) variable? What are the controlled variables?

When conducting a controlled experiment, change only one manipulated variable at a time, holding all the others (except the responding variable) constant. This way, you can assume that the results are caused by the manipulated variable and not by any of the other variables.

HYPOTHESIS

When formulating a hypothesis, first read the testable question, the experimental design, and the procedure. Then try to identify (and distinguish) the manipulated variable, the responding variable, and the controlled variables. Your hypothesis will be a predicted answer to your testable question accompanied by a theoretical explanation for your prediction.

EXPERIMENTAL DESIGN

The design of a controlled experiment shows how you plan to answer your question. The design outlines how you will change the manipulated variable, measure any variations in the responding variable, and control all the other variables. It is a summary of your plan for the experiment.

EQUIPMENT AND MATERIALS

Make a detailed list of all equipment and materials used, including sizes and quantities where appropriate. Be sure to include safety equipment, such as eye protection, lab apron, protective gloves, and tongs, where needed. Draw a diagram to show any complicated setup of apparatus.

PROCEDURE

Write a step-by-step description of how you will perform your investigation. It must be clear enough for someone else to follow and it must explain how you will deal with each of the variables in your investigation. The first step in a procedure usually refers to any safety precautions that need to be addressed, and the last step relates to any cleanup that needs to be done.

OBSERVATIONS

There are many ways you can gather and record observations during your investigation. It is helpful to plan ahead and think about what data you will need to answer the question and how best to record them (for example, data tables, pictures, or labelled diagrams may be helpful). This helps to clarify your thinking about the question posed at the beginning, the variables, the number of trials, the procedure, the materials, and your skills. It will also help you organize your evidence for easier analysis.

ANALYZE AND EVALUATE

You will need to analyze and interpret your observations—this may include graphing your data and analyzing any patterns or trends that may be evident in your graphs. After thoroughly analyzing your observations, you may have sufficient and appropriate evidence to enable you to answer the testable question posed at the beginning of the investigation.

You must evaluate the processes that you followed to plan and perform the investigation. You must also evaluate the outcome of the investigation, which involves evaluating your hypothesis/prediction. You must identify and take into account any sources of error and uncertainty in your measurements.

Finally, compare your hypothesis/prediction with the evidence. Is your hypothesis supported by the evidence?

APPLY AND EXTEND

Reflect on how your investigation relates to the world around you: how can you use what you have learned in everyday life?

REPORTING ON THE INVESTIGATION

Your lab report should describe your planning process and procedure clearly and in enough detail that the reader could repeat the experiment exactly as you performed it. You should present your observations, analysis, and evaluation of your experiment clearly, accurately, and honestly.

A2.3 Correlational Studies

When the purpose of scientific inquiry is to test a suspected relationship between two different variables, but a controlled experiment is not possible, a correlational study is conducted. In a correlational study the investigator tries to determine whether one variable is affecting another without purposely changing or controlling any of the variables. Instead, variables are allowed to change naturally. It is often difficult to isolate cause and effect in correlational studies. A correlational study requires very large sample numbers and many replications to increase the certainty of the results.

A correlational study does not require experiments or fieldwork; for example, the investigator can use databases prepared by other researchers to find relationships between two or more variables. The investigator can, however, choose to also make observations and measurements through fieldwork, interviews, and surveys.

A hypothesis or prediction is not needed in a correlational study. Correlational studies are not intended to establish cause-and-effect relationships. However, the results of a correlational study can be used to formulate a hypothesis about the causal relationship between the variables.

The common components of a correlational study are outlined below. Even though the sequence is presented as linear, there are normally many cycles through the steps during an actual study.

PURPOSE

When planning a correlational study, it is important that you pose a question about a possible statistical relationship between variable A and variable B. Choose a topic that interests you. Determine whether you are going to replicate or revise a previous study, or create a new one. Indicate your decision in the statement of the purpose.

VARIABLES

In a correlational study you must determine whether two variables are related, without controlling any of the variables. Correlation is the degree to which two sets of data vary together. You must identify all the major variables that will be measured and/or observed in your investigation.

STUDY DESIGN

When designing your correlational study you must identify the setting and the methods you will use in carrying out your investigation. You should describe the type(s) of data you plan

to collect and its sources. Your design should address questions such as the following: Will you be conducting a survey? If so, where will the survey be conducted? Who will answer your questionnaire? When will the survey be conducted? How often will the survey be administered? If you are obtaining information from an existing database, then describe the source of the information and your plans for analyzing the information.

EQUIPMENT AND MATERIALS

Make a detailed list of all equipment and materials used, including sizes and quantities where appropriate. Be sure to include safety equipment, such as eye protection and ear protection, where needed. Draw a diagram to show any complicated setup of apparatus.

PROCEDURE

Write a step-by-step description identifying how you will gather data on the variables under study. You will also need to identify potential sources of data. There are two possible sources: observations made by you, the investigator, and existing data (databases, and so on).

OBSERVATIONS

If you are collecting your own data through observation then you will need to plan ahead and think about what data you will need and how best to record them. There are many ways to gather and record your observations (such as data tables, pictures, or labelled diagrams). This is an important step because it helps to clarify your thinking about the question posed at the beginning, the variables, the procedure, the materials, and your skills. It will also help you organize your observations for easier analysis.

ANALYZE AND EVALUATE

You will need to analyze and interpret your observations or sourced data—this will usually include graphing the data and analyzing any patterns or trends that may be evident in your graphs. You will need to identify the relationship between your two variables. A positive correlation indicates a direct relationship between variables: an increase in one variable corresponds to an increase in another (**Figure 1(a)**). A negative correlation indicates an inverse relationship: an increase in one variable corresponds to a decrease in the other variable (**Figure 1(b)**). If there is no relationship between the variables then there is no correlation (**Figure 1(c)**).

When you know that two variables are correlated, you can predict one variable based on the other. Generally, the stronger the correlation, the more probable it is that your prediction will be correct. After analyzing your observations, revisit the question you posed at the beginning of the investigation. Is there a relationship between variable A and variable B?

Evaluate the processes that you followed to plan and perform the investigation. Also evaluate the outcome of the investigation, which involves evaluating any prediction you made at the beginning of the investigation. You must identify and take into account any sources of error and uncertainty in your measurements.

APPLY AND EXTEND

Reflect on how your investigation relates to the world around you: how can you use what you have learned in your everyday life?

REPORTING ON THE INVESTIGATION

In preparing your report, your objectives should be to describe your design and procedure accurately and to report your observations, analyses, and evaluations accurately and honestly.

A2.4 Observational Studies

Often, the purpose of an inquiry is simply to study a natural phenomenon with the intention of gaining scientifically significant information to answer a question. Observational studies involve observing a subject or phenomenon in an unobtrusive or unstructured manner, usually with no specific hypothesis. The inquiry does not start off with a hypothesis, but a hypothesis may be generated as information is collected.

The stages and processes of scientific inquiry through observational studies are summarized below. Even though the sequence is presented as linear, there are normally many cycles through the steps during an actual study.

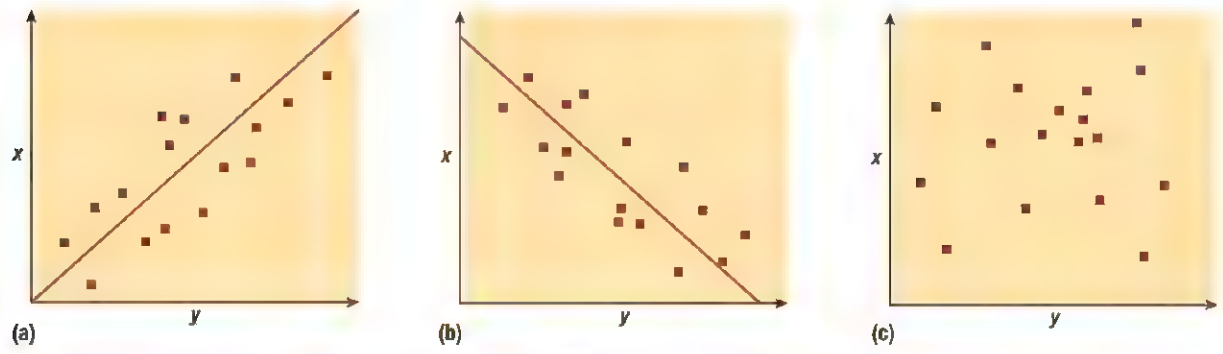


Figure 1 (a) In a positive correlation, variable *y* increases as variable *x* increases. (b) In a negative correlation, *y* decreases as *x* increases. (c) If there is no correlation, there is no pattern.

PURPOSE

In planning an observational study, it is important to pose a general question about the natural world. Choose a topic that interests you. Determine whether you are going to replicate or revise a previous study, or create a new one. Indicate your decision in a statement of the purpose.

EQUIPMENT AND MATERIALS

Make a detailed list of all equipment and materials used, including sizes and quantities where appropriate. Be sure to include safety equipment, where needed. Draw a diagram to show any complicated setup of apparatus.

PROCEDURE

Write a step-by-step description of how you will make your observations. The first step in a procedure usually refers to any safety precautions that need to be addressed, and the last step relates to any cleanup that needs to be done.

OBSERVATIONS

There are many ways you can gather and record observations—including quantitative observations—during an observational study. All observations should be objective. Consider ways to organize your information for easier analysis.

ANALYZE AND EVALUATE

After thoroughly analyzing your observations, you may have sufficient and appropriate evidence to enable you to answer the question posed at the beginning of the investigation. You may also have enough observations and information to form a hypothesis for a controlled experiment.

At this stage of the investigation, you will evaluate the processes used to plan and perform the investigation. Evaluating the processes includes evaluating the materials, the design, the procedure, and your skills. The results of most such investigations will suggest further studies, perhaps controlled experiments or correlational studies, to explore tentative hypotheses you may have developed.

APPLY AND EXTEND

At this stage you should reflect on how your investigation relates to the world around you: how can you use what you have learned in your everyday life?

REPORTING ON THE INVESTIGATION

In your report, describe your design and procedure accurately, and report your observations accurately and honestly.

A2.5 Field Studies

A field study is a special case of observational study. The investigation is being conducted outside of the classroom setting and will require special planning and considerations. In most cases, there will be special safety considerations to take into account since the study is conducted in a natural environment. If a field study is conducted near a pond, lake, or stream, then water safety needs to be taken into consideration. Since field studies often involve studying living organisms in their natural environment, it is important to consider how the study will affect the biotic and abiotic components of the environment. The investigator should take steps to minimize any potentially negative effects on the organisms being studied or their environment.

A2.6 Lab Reports

When carrying out investigations, it is important that scientists keep records of their plans and results, and share their findings. In order to have their investigations repeated (replicated) and accepted by the scientific community, scientists generally share their work by publishing reports in which details of their design, materials, procedure, evidence, analysis, and evaluation are provided.

Lab reports are prepared after an investigation is completed. To ensure that you can accurately describe the investigation, keep thorough and accurate records of your activities as you carry out the investigation.

Your lab book or report should reflect the type of scientific inquiry that you used in the investigation (controlled experiment, correlational study, observational study, or field study) and should be based on the following headings, *as appropriate*:

TITLE

At the beginning of your report, write the number and title of your investigation. If you are designing your own investigation, create a title that suggests what the investigation is about. Include the date the investigation was conducted and the names of all lab partners.

PURPOSE

State the purpose of the investigation. Why are you doing this investigation?

TESTABLE QUESTION

State the question that you attempted to answer in the investigation. Sometimes the question is provided for you; other times you are expected to formulate your own. If it is appropriate to do so, state the question in terms of manipulated and responding variables.

HYPOTHESIS/PREDICTION

For a controlled experiment you will usually have to compose a hypothesis or prediction. This will be a proposed answer to your testable question. When writing a hypothesis include both a prediction and a reason for the prediction, based on scientific theory, law, or other generalization. You may use the "If . . . , then . . . because . . ." form. A simple prediction may be written in the "If . . . , then . . ." form.

VARIABLES

Identify all major variables that you measured and/or controlled in the investigation. What is the manipulated variable? What is the responding variable? What are the major controlled variables?

EXPERIMENTAL DESIGN

Provide a brief general overview (one to three sentences) of what you did in your investigation. If your investigation involved manipulated, responding, and controlled variables, list them and indicate how they were changed, measured, or held constant. Identify any control or control group that was used in the investigation.

EQUIPMENT AND MATERIALS

Include a detailed list of all equipment and materials used, including sizes and quantities where appropriate. Be sure to include safety equipment, such as eye protection, lab apron, protective gloves, and tongs, where needed. Draw a diagram to show any complicated setup of apparatus.

PROCEDURE

Describe, in detailed numbered steps, the procedure you followed to carry out your investigation. Your teacher may specify which style you should use. Examples of three common writing styles are

1. passive tense ("The test tubes were heated . . .")
2. first person plural past tense ("We heated the test tubes . . .")
3. second person imperative ("Heat the test tubes . . .")

Include steps to clean up and dispose of waste.

OBSERVATIONS

Present your observations in a form that is easily understood. This includes all the qualitative and quantitative observations that you made. Be as precise as possible when describing quantitative observations. Include any unexpected observations and present your information clearly. If you have only a few observations, this could be a list; for controlled experiments and for many observations, a data table, labelled diagram, or written descriptions would be more appropriate.

ANALYSIS

Complete the questions found in the Analyze and Evaluate section of the investigation. These questions will prompt you to analyze and interpret your observations, answer a testable question, draw conclusions, and evaluate both your experiment and your conclusions. You will also be prompted to graph your data and analyze these graphs where applicable.

If you are writing up an investigation for which there are no questions, write your own analysis. Interpret your observations and present the evidence in the form of titled tables, graphs, or illustrations, as appropriate. Include any calculations, the results of which can be shown in a table. Make statements about any patterns or trends you observed. Conclude the analysis with a statement based only on the evidence you have gathered, answering the question that initiated the investigation.

EVALUATION

The evaluation is your judgment about the quality of evidence obtained and about the validity of the prediction and hypothesis (if present). This section can be divided into two parts:

(1) Evaluation of the experiment: Did your experiment provide reliable and valid evidence to enable you to answer the question? Consider the experimental design, the procedure, and your laboratory skills. Were they all adequate? Are you confident enough in the evidence to use it to evaluate any prediction and/or hypothesis you made?

(2) Evaluation of the prediction: Was the prediction you made before the investigation supported or falsified by the evidence? Based on your evaluation of the evidence and prediction, is the hypothesis you used to make your prediction supported, or should it be rejected?

APPLY AND EXTEND

Answer any Apply and Extend questions in the investigation. Number your answers as they appear in the Apply and Extend section in the textbook.

A3 Laboratory Skills and Techniques

A3.1 Dissection

Dissection tools are very sharp and must be handled carefully. Read through the following safety tips before you begin any dissections (**Figure 1**).

- Always hold the dissection tool by the handle.
- To move dissection equipment to and from your workstation, place all tools in the dissection tray and carry the tray with both hands. Do not carry tools by hand. If you forget a piece of equipment, carry the tray back to get what you need.
- At your workstation, imagine your dissection tray sitting in the middle of a 30 cm circle (about the size of a large dinner plate). The tools never leave this circle. If you leave your workstation or turn to answer a question, place the tools in the dissection tray. Tools must always lie flat on the inside or outside of the dissecting tray, not propped up on the side of the tray.
- Always cut away from yourself and others. Cut downward onto a tray.
- If you are asked to rinse a tool after you have used it, remember that the tool is sharp. Hold it by the handle and rinse it under running water; do not wipe sharp edges or points.

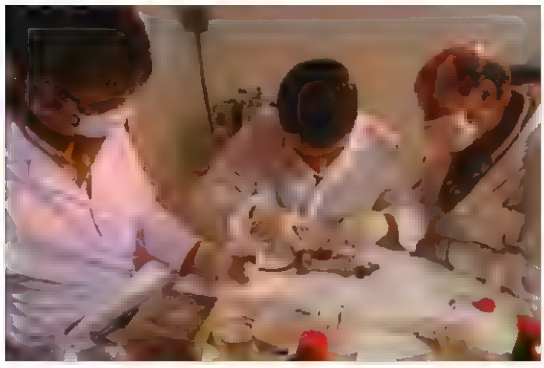


Figure 1 Use safety equipment and always work within a 30 cm circle at your workstation when dissecting.

A3.2 Biological Drawings

Biological drawings are an essential part of recording your observations, both microscopic and macroscopic. These drawings are used to communicate, so it is very important that they be as accurate as possible, clear, well labelled, and easy to understand. You will be required to make drawings of external features of whole specimens, parts of specimens, dissections, and prepared slides.

PREPARATION

- Use plain, white paper and a sharp, hard pencil. Sharpen your pencil often to ensure clear, fine lines.
- Create drawings large enough to show details. For example, a third of a page might be appropriate for a diagram of a single cell or a unicellular organism. When drawing lab equipment, do not include unnecessary details.
- Label your diagram clearly. Use a ruler to draw the label lines.

DRAWING TIPS

- Draw only what you see. Do not copy diagrams from books or draw what you think you should see.
- Use firm, clear lines. When recording microscope observations, use only the outline of structures for low-power observations; show details in high-power observations (**Figure 2**).

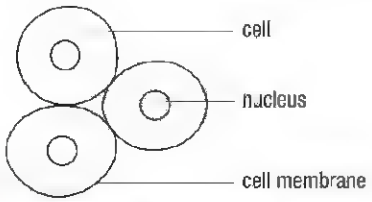


Figure 2 Clear, solid lines showing outlines of cells

- If important details are too small to be shown clearly, they should be shown in an enlarged drawing on the side.
- Do not use colouring or shading. To show darker areas, stippling (dots) may be used. Draw double lines to indicate thick structures (**Figure 3**).

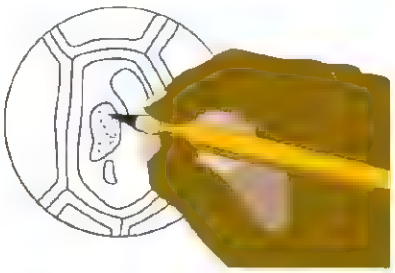


Figure 3 Use stippling to show darker areas and double lines to show thick structures.

- If a specimen shows repetitive structures, it is sufficient to draw only a representative section in detail (**Figure 4**).
- Do not draw on both sides of the paper.

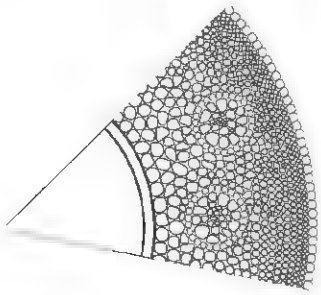


Figure 4 A representative drawing of a stem cross-section

LABELLING

- All important structures should be labelled clearly. Always use the singular form for the labels (for example, chloroplast, not chloroplasts).
- Connect labels to the appropriate parts using only horizontal lines if possible (**Figure 5**).

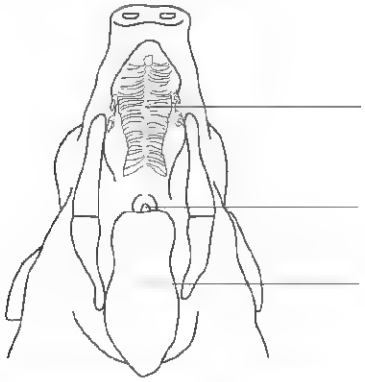


Figure 5 Connect your labels with horizontal lines.

- Do not label too close to the drawing, and never write on the drawing itself. It is preferable to list your labels in an even column down the right side (**Figure 6**).

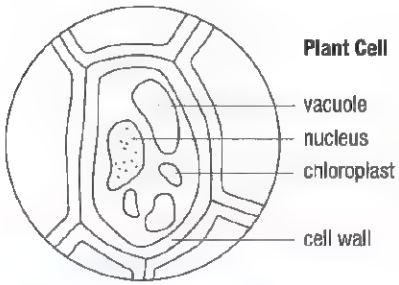


Figure 6 Neat labelling makes your drawing clear.

- For drawings of microscope observations, indicate the magnification.
- Title the drawing. Use the name of the specimen and any other information that will help identify the drawing. Underline the title.

SCALE RATIO

You may want to indicate the actual size of your object on your drawing. To do this, use a ratio called the scale ratio.

- If your diagram is 10 times as large as the real object (for example, a tiny organism), your scale ratio is 10×.
- In general, scale ratio $= \frac{\text{size of drawing}}{\text{actual size of object}}$

You can also show the actual size of the object on your diagram.

A3.3 Care and Use of the Microscope

The microscope (**Figure 7**) is a useful tool in making observations and collecting data during scientific investigations in biology.

Figure 7 A compound light microscope

The eyepiece lens usually magnifies 10 times. This information is printed on the side of the eyepiece. The microscopes that you will likely use will have three objective lenses: low (magnifies 4 times), medium (magnifies 10 times), and high (magnifies 40 times). To determine the total magnification, multiply the magnification of the eyepiece lens by the magnification of the objective lens. For example, the magnification obtained using the medium-power objective lens is 10 times multiplied by 10 times, or 100 times. In other words, a specimen viewed with the medium-power lens will appear 100 times as large as it actually is.

To view very small specimens, an oil immersion lens can be attached to the revolving nosepiece. This lens magnifies 100 times. A drop of immersion oil is placed between the slide and this objective lens.

PRACTICE USING THE COMPOUND MICROSCOPE

1. Obtain a microscope from the storage area. Grasp the arm with one hand and use the other to support the base of the microscope.
2. If the microscope has a built-in light supply, plug it in. Place the cord so that it will not be hooked accidentally.
3. Rotate the revolving nosepiece until the shortest (low-power) objective lens clicks into place.
4. Place a prepared slide of the letter *f* on the stage and centre it. Hold the slide in place with the stage clips.
5. Turn the coarse-adjustment knob away from you to lower the lens down as far as possible. Watch from the side to ensure that the lens does not contact the slide.
6. Keeping both eyes open, look through the eyepiece and turn the coarse-adjustment knob toward you until the object comes into view. Use the fine-adjustment knob to focus the image.
7. Adjust the diaphragm to control the amount of light and fix the contrast. If the microscope has a mirror in the base, adjust it to receive the appropriate amount of light.
8. Compare the orientation of the letter *f* as viewed on the slide with the orientation as viewed through the eyepiece.
9. Compare the movement of the object on the slide with the movement of the object as viewed through the eyepiece.
10. With the image in focus and centred in the field of view, rotate the nosepiece until the medium-power objective lens clicks into place.
11. Use the fine-adjustment knob to refocus the image if necessary.
12. Readjust the diaphragm to regulate the amount of light. The higher the lens power, the more light is necessary.
13. Repeat the previous three steps with the high-power lens.
14. View other prepared slides to practise locating objects within the field of view and focusing the microscope.
15. When you have finished viewing a specimen, always rotate the nosepiece so that the shortest (low-power) lens is centred before making any adjustments with the focusing knobs.
16. If you have used a wet mount slide, remove and clean the slide and cover slip and return them to their appropriate location.
17. Return the microscope to the storage area.

INVESTIGATING DEPTH OF FIELD

The depth of field is the amount of an image that is in sharp focus when it is viewed under a microscope.

1. Cut two pieces of thread of different colours.
2. Make a temporary dry mount by placing one thread over the other in the form of an X in the centre of a microscope slide. Cover the threads with a cover slip.
3. Place the slide on the microscope stage and turn on the light.
4. Position the low-power objective lens close to, but not touching, the slide.
5. View the crossed threads through the ocular lens (eyepiece). Slowly rotate the coarse-adjustment knob until the threads come into focus.
6. Rotate the nosepiece to the medium-power objective lens. Focus on the upper thread by using the fine adjustment knob. You will probably notice that you cannot focus on the lower thread at the same time. The depth of the object that is in focus at any one time represents the depth of field.
7. Repeat Step 6 for the high-power objective lens.
   Note: The stronger the magnification, the shallower the depth of field.

DETERMINING THE FIELD OF VIEW

It is often necessary to measure the size of objects viewed through the microscope. The field of view is the circle of light seen while looking through the eyepiece. Once the size of the field of view is determined, it is possible to estimate the size of a specimen by comparing it to the size of the field of view.

1. With the low-power lens in place, put a transparent ruler on the stage. Position the millimetre marks on the ruler immediately below the objective lens.
2. Using the coarse-adjustment knob, focus on the marks on the ruler.
3. Move the ruler so that one of the millimetre markings is just at the edge of the field of view. Note the diameter of the field of view in millimetres under the low-power objective lens.
4. Using the same procedure, measure the field of view for the medium-power objective lens.
5. Most high-power lenses provide a field of view that is less than one millimetre in diameter, so it cannot be measured with a ruler. The following steps can be followed to calculate the field of view of the high-power lens.

- Calculate the ratio of the magnification of the high-power lens to that of the low-power lens.

$$\text{ratio} = \frac{\text{magnification of high-power lens}}{\text{magnification of low-power lens}}$$

- Use the ratio to determine the diameter of the field of view under high-power magnification.

$$\text{field of view diameter (high-power)} = \frac{\text{field of view diameter (low-power)}}{\text{ratio}}$$

6. Using a table like **Table 1**, determine the magnification of each of the lenses on your microscope and record the diameter of the field of view.

Table 1 Magnification of Lenses

Lens	Magnification	Eyepiece magnification	Total magnification	Diameter (mm)
low		10×		
medium		10×		
high		10×		

ESTIMATING SIZE

- Determine the size of the field of view you are viewing.
- Estimate the length and width of the specimen by comparing it to the diameter of the field of view.
- **Figure 8** shows a skin cell viewed under high power. One might estimate it to be 0.2 mm wide.

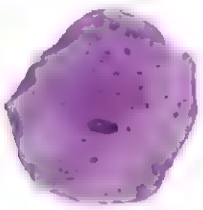


Figure 8

A3.4 Preparing Slides and Staining Techniques

PREPARING A WET-MOUNT SLIDE

Specimens of all types can be mounted in a fluid medium before they are examined. Water is the most convenient, but 30 % glycerol can also be used. Glycerol helps make the material more transparent and it does not dry out as fast as water. A cover slip is used so that there are no reflecting surfaces and to keep the lens from coming in contact with the specimen.

1. Clean a slide and cover slip, holding them by the edges so that you do not leave fingerprints on them. Lay them on a clean, dry surface.
2. Place a drop of water or glycerol in the centre of the slide.
3. Transfer the specimen into the water.
4. Hold the edges of the cover slip between thumb and forefinger. Place the cover slip in an almost vertical position on the slide so that the cover slip just touches the edge of the drop of water or glycerol (**Figure 9**).

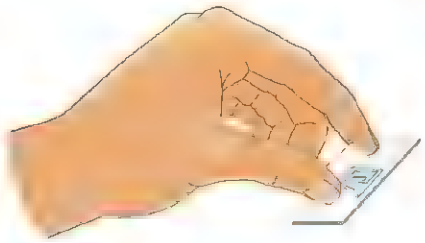


Figure 9

5. The water or glycerol will spread along the edge of the cover slip. Supporting the cover slip with the point of a needle, gently lower the cover slip onto the slide.
6. Use blotting paper to dry off any excess water or glycerol around the cover slip. Dry any water that may accidentally drop onto the stage of the microscope or on the objective lenses.

STAINING TECHNIQUES

Staining procedures are used to increase the contrast between cells of various tissues and the mounting medium, and to make the features more visible. Biological stains may be temporary or permanent. In this course, we are not concerned with creating permanent slides, so temporary staining is adequate. Stains react differently with different components of cells; they may affect the cell walls, they may stain the cytoplasm, or they may be used as a test for a specific substance (for example, iodine for starch). There are many stains available, but those listed below are more common. In most cases, the staining technique is simple. After a wet-mount slide has been prepared, a drop of the stain is placed beside and under one corner of the cover slip. A piece of paper towel or filter paper touched to the water on the opposite side of the cover slip will draw the stain through the entire specimen in a few seconds. The stained specimen may then be observed.

LUGOL'S (IODINE) SOLUTION

This is an especially good stain for plant cells like onion cells. A weak solution of iodine in potassium iodide is a specific colour indicator for starch; it turns blue-black. Starch grains in tissues show up very clearly. Cellulose cell walls remain unstained. Sections may be mounted directly in iodine as described above.

ANILINE SULFATE

Lignified walls of plant cells turn bright yellow. Specimens may be left in aniline sulfate or transferred to glycerol.

SUDAN IV INDICATOR

A saturated solution of Sudan IV in 70 % alcohol will stain all fatty substances orange-pink or red. Fresh sections should be left in the stain for 20 min.Wash with 50 % alcohol to remove excess stain and transfer to a drop of glycerol. Fats can be detected as droplets within cells.

TOLUIDINE BLUE

This is an excellent water-soluble double stain. Lignified cell walls stain green, greenish blue, or bright blue. Lignified phloem fibres stain bright blue, and xylem elements stain a greenish colour. Most nonlignified cell walls (for example, parenchyma) stain pinkish purple. Nuclei become visible and chloroplasts keep their distinctive green colour. Specimens should be left in stain for approximately 30 s, rinsed with water, and then wet-mounted.

A3.5 Using the Stethoscope and Sphygmomanometer

USING THE STETHOSCOPE

Always use the stethoscope in a quiet area to ensure that the sounds from the body are not overpowered by background noises. The stethoscope should also always be used on bare skin.

Never tap the surface of the stethoscope while it is being worn—this can produce a very loud sound and potentially cause ear damage.

Place the two earpieces of the stethoscope in your ears. They should fit snugly in your ears. Be sure that they fit comfortably and do not hurt your ears.

Hold the round part of the stethoscope up to a person's chest, approximately where the heart is located. You should hear a steady *lubb-DUBB* sound.

USING THE SPHYGMOMANOMETER

Wrap the cuff of the sphygmomanometer around the upper arm just above the elbow. It should be snug but not tight.

Ensure the round end of the stethoscope is on the inside of the cuff just above the bend of the elbow on the inside of the arm. Place the stethoscope in your ears. Close the valve by turning it clockwise. While carefully watching the gauge, pump air into the cuff until the pressure gauge reaches 200 mm Hg.

Turn the valve counterclockwise and begin to slowly and steadily release the air. As the air escapes, use the stethoscope to listen for a pulse. When you first hear heart sounds, record the value on the gauge. This is the systolic pressure.

Continue to slowly release air and listen to the beating sounds of the heart. The sound will soon fade. The instant you can no longer hear the pulse, record the number on the gauge. This is the diastolic pressure.

A4 Scientific Publications

Communicating in Science

Advances in science and our understanding of the natural world are the result of scientists sharing ideas and information. Watson and Crick won the Nobel Prize for discovering the double helix structure of DNA, but they solved this structure with the help of X-ray photographs taken by Rosalind Franklin during her own research.

It is important for scientists to share ideas and research with other scientists. New research findings are shared at conferences or in journal publications. Research scientists take pride in being published. Being published confirms that the research adds to the knowledge base of the scientific community. Sharing information helps to spread knowledge, solve problems, and inspire other scientists.

The Scientific Journal

Scientific journals are publications that are used to present new research. There are thousands of different science journals published worldwide, and in many languages. A scientific journal may be specific to a subject (for example, *Canadian Journal of Diabetes*) or contain articles that cover a variety of subjects within a field (for example, *Nature*). These publications may be electronic (online) or in print and may be published weekly, monthly, bimonthly, or quarterly.

Peer Review

When an article is submitted to a journal the research findings are critically reviewed by experts in that subject or field. This ensures that the research presents ideas that are supported by practices of good science. High quality evidence and appropriate conclusions are necessary for the article to be accepted for publication. An article that is submitted to a reputable journal may take months to be approved for publication. The article may be returned to the author(s) for revision if necessary.

Scientists aim to be published in the most respected journals. The peer-review process contributes to the reputation of a journal. It helps to maintain standards and provide credibility. A scientific journal becomes reputable by ensuring that only articles of high quality are published. Very prestigious journals (such as *Nature*, *Science*, and *New England Journal of Medicine*) are known for publishing research backed by only the best practices of science. Reputable journals are widely read and considered reliable by the scientific community. Publication in a reputable journal brings immediate recognition for the author(s). Research that is not published in a peer-reviewed journal is often overlooked or disregarded.

Format of Research Articles

Research articles have specific sections. Articles often include an abstract, introduction, methods, results, discussion, conclusions, and references.

THE ABSTRACT

The abstract is a short summary of the article. It presents the purpose of the research, outlines the design of the experiment and methods used, and summarizes findings or conclusions. A well-written abstract is useful when looking for articles with specific information. Time may be saved by reading the abstract and then deciding if the article is going to be helpful in supporting research.

CITING SOURCES AND GIVING CREDIT

Once a scientist has found useful sources and included them in an article or paper, information must be provided about the sources so that someone else who is interested in learning more will be able to find them. This also shows the reader that information supporting the research is current.

More importantly, citing another scientist's work provides a measure of value of what he or she has published. It gives credit to the scientist. More citations often mean that the work is worthwhile and influential. An example of this is the frequency of citation of Kary Mullis's work that presented the polymerase chain reaction (PCR)—an important advance in genetics for copying DNA fragments. Thousands of citations occurred within a few years of publication, confirming that his work was influential.

Further Reading

Day, R.A., & Gastel, B. (2006). *How to write and publish a scientific paper* (6th ed.). Cambridge: Cambridge University Press.

A5 Exploring Issues and Applications

Throughout this textbook you will have many opportunities to examine the connections between science, technology, society, and the environment (STSE) by exploring issues and applications.

An issue is a situation in which several points of view need to be considered in order to make a decision. There can be many positions, generally determined by the values that an individual or a society holds, on a single issue. Which solution is "best" is a matter of opinion; ideally, the solution that is implemented is the one that is most appropriate for society as a whole. Researching information about an issue will help you make an educated decision about it. All the skills listed in Section A5.1 may be useful in an activity that involves exploring an issue.

Scientific research produces knowledge or understanding of natural phenomena. Technologists and engineers look for ways to apply this knowledge in the development of practical products and processes. Technological inventions and innovations can have wide ranging applications for, and impacts on, society and the environment. The purpose of exploring an application is to research a particular technological invention or innovation to determine how it works, how it is used, and how it may affect society and the environment. The skills of researching, communicating, and evaluating may be useful in an activity that involves exploring an application.

A5.1 Research Skills

The following skills are involved in many types of research. Some of these skills will help you research issues only, while some will help you research issues or applications. Refer to this section when you have questions about any of the following skills and processes.

DEFINING THE ISSUE

When exploring an issue, the first step in understanding the issue is to explain why it exists, the problems associated with it, and, if applicable, the individuals or groups, also known as stakeholders, that are involved in it. The issue includes information about the role a person takes when thinking about an issue as well as a description of who your audience will be. You could brainstorm questions involving Who? What? Where? When? Why? and How? Develop background information on the issue by clarifying facts and concepts, and identifying relevant attributes, features, or characteristics of the problem.

RESEARCHING

When beginning your research for both issues and applications, you need to formulate a research question that helps to limit, narrow, or define the scope of your research. You then need to develop a plan to find reliable and relevant sources of information. This includes outlining the stages of your research: gathering, sorting, evaluating, selecting, and integrating relevant information. You should gather information from a variety of sources if possible (for example, print, web, and personal interviews).

As you collect information, do your best to ensure that the information is reliable, accurate, and current. Avoid biased opinions: those that are not supported by or that ignore credible evidence. It is important to ensure that the information you have gathered addresses all aspects of the issue or application you are researching.

IDENTIFYING ALTERNATIVES

When exploring an issue, examine the situation and think of as many alternative solutions as you can. Be creative about combining the solutions. At this point, it does not matter if the solutions seem unrealistic. To analyze the alternatives, you should examine the issue from a variety of perspectives. Stakeholders may bring different viewpoints to an issue and these may influence their position on the issue. Brainstorm or hypothesize how different stakeholders would feel about your alternatives.

ANALYZING THE ISSUE

An important part of exploring an issue is analyzing the issue. First, you should establish criteria for evaluating your information to determine its relevance and significance. You can then evaluate your sources, determine what assumptions may have been made, and assess whether you have enough information to make your decision.

To effectively analyze an issue you should

- establish criteria for determining the relevance and significance of the data you have gathered
- evaluate the sources of information
- identify and determine what assumptions have been made
- challenge unsupported evidence
- evaluate the alternative solutions, possibly by conducting a risk–benefit analysis

Once the issue has been analyzed, you can begin to evaluate the alternative solutions. You may decide to carry out a risk–benefit analysis—a tool that enables you to look at each possible result of a proposed action and helps you make a decision (see Section A5.2 for more information.)

DEFENDING A DECISION

After analyzing your information on your issue, you can answer your research question and take an informed position or draw a conclusion on the issue. If you are working as a group, this is the stage where everyone gets a chance to share ideas and information gathered about the issue. Then the group needs to evaluate all the possible alternatives and decide on their preferred solution based on the criteria.

Your position on the issue or conclusion must be justified using supporting information that you have researched. You

should be able to defend your position to people with different perspectives. Ask yourself the following questions:

- Do I have supporting evidence from a variety of sources?
- Can I state my position clearly?
- Can I show why this issue is relevant and important to society?
- Do I have solid arguments (with solid evidence) supporting my position?
- Have I considered arguments against my position and identified their faults?
- Have I analyzed the strong and weak points of each perspective?

COMMUNICATING

When exploring an issue, there are several things to consider when communicating your decision. You need to state your position clearly and take into consideration who your audience is. You should always support your decision with objective data and a persuasive argument if possible. Be prepared to defend your position against any opposition.

You should be able to defend your solution in an appropriate format – debate, class discussion, speech, position paper, multimedia presentation, brochure, poster, video, etc.

When exploring an application you should communicate the "need or want" for the application (why the application was developed in the first place), the "how" (how the application/technology actually works), and the risks and benefits to society, individuals, and the environment. You should conclude with your "assessment" of the application.

EVALUATING

The final phase of your decision making when exploring an issue includes evaluating the decision itself and the process used to reach the decision. After you have made a decision, carefully examine the thinking that led to your decision.

Some questions to guide your evaluation include:

- What was my initial perspective on the issue? How has my perspective changed since I first began to explore the issue?
- How did I make my decision? What process did I use? What steps did I follow?
- To what extent were my arguments factually accurate and persuasively made?
- In what ways does my decision resolve the issue?
- What are the likely short- and long-term effects of the decision?
- To what extent am I satisfied with the final decision?
- What reasons would I give to explain our decision?
- If I had to make this decision again, what would I do differently?

A5.2 Risk–Benefit Analysis Model

Risk–benefit analysis is a tool used to organize and analyze information gathered in research, especially when exploring a socio-scientific issue. A thorough analysis of the risks and benefits associated with each alternative solution can help you decide on the best alternative.

- Research as many aspects of the situation as possible. Look at it from different perspectives.
- Collect as much evidence as you can, including reasonable projections of likely outcomes if the proposal is adopted.
- Classify every individual potential result as being either a benefit or a risk.
- Quantify the size of the potential benefit or risk (perhaps as a dollar figure, or a number of lives affected, or on a scale of 1 to 5).
- Estimate the probability (percentage) of that event occurring.
- By multiplying the size of a benefit (or risk) by the probability of its happening, you can calculate a probability value for each potential result.
- Total the probability values of all the potential risks and all the potential benefits.
- Compare the sums to help you decide whether to accept the proposed action.

A6 Math Skills

A6.1 Scientific Notation

It is difficult to work with very large or very small numbers when they are written in common decimal notation. Usually it is possible to accommodate such numbers by changing the SI prefix so that the number falls between 0.1 and 1000. For example, 237 000 000 mm can be expressed as 237 km, and 0.000 000 895 kg can be expressed as 0.895 mg. However, this prefix change is not always possible, either because an appropriate prefix does not exist or because it is essential to use a particular unit of measurement in a calculation. In these cases the best method of dealing with very large and very small numbers is to write them using scientific notation. Scientific notation expresses a number by writing it in the form $a \times 10^n$, where $1 < |a| < 10$ and the digits in the coefficient a are all significant. **Table 1** shows situations where scientific notation would be used.

Table 1 Examples of Scientific Notation

Expression	Common decimal notation	Scientific notation
"124.5 million kilometres"	124 500 000 km	1.245×10^8 km
"154 thousand picometres"	154 000 pm	1.54×10^5 pm (or 1.54×10^{-7} m)
"602 sextillion molecules"	602 000 000 000 000 000 000 000 molecules	6.02×10^{23} molecules

To multiply numbers in scientific notation, multiply the coefficients and add the exponents. To divide numbers in scientific notation, divide the coefficients and subtract the exponents. The answer is always expressed in scientific notation. Note that the coefficient should always be between 1 and 10. For example,

$$(4.73 \times 10^5 \text{ m})(5.82 \times 10^7 \text{ m}) = 27.5 \times 10^{12} \text{ m}^2 - 2.75 \times 10^{13} \text{ m}^2$$

$$\frac{(6.4 \times 10^6 \text{ m})}{(2.2 \times 10^3 \text{ s})} = 2.9 \times 10^3 \text{ m/s}$$

When evaluating exponents, the following rules apply:

$$x^a \cdot x^b = x^{a+b} \qquad (xy)^b = x^b y^b$$

$$\frac{x^a}{x^b} = x^{a-b} \qquad \left(\frac{x}{y}\right)^b = \frac{x^b}{y^b}$$

$$(x^a)^b = x^{ab}$$

SCIENTIFIC NOTATION WITH CALCULATORS

On many calculators, scientific notation is entered using a special key, labelled EXP or EE. This key includes "$\times 10$" from the scientific notation; you need to enter only the exponent. For example, to enter

7.5×10^4 press 7.5 EXP 4

3.6×10^{-3} press 3.6 EXP +/− 3

Depending on the type of calculator you have, +/− may need to be entered after the relevant number.

A6.2 Uncertainty in Measurements

There are two types of quantities that are used in science: exact values and measurements. Exact values include defined quantities (1 m = 100 cm) and counted values (5 beakers or 10 trials). Measurements, however, are not exact because there is some uncertainty or error associated with every measurement

SIGNIFICANT DIGITS

The certainty of any measurement is communicated by the number of significant digits in the measurement. In a measured or calculated value, significant digits are the digits that are known reliably, or for certain, and include the last digit that is estimated or uncertain. Significant digits include all digits correctly reported from a measurement.

Follow these rules to decide if a digit is significant:

1. All non-zero digits are significant.
2. If a decimal point is present, zeros to the left of other digits (leading zeros) are not significant.
3. If a decimal point is not present, zeros to the right of the last non-zero digit (trailing zeros) are not significant.
4. Zeros placed between other digits are always significant.
5. Zeros placed after other digits to the right of a decimal point are significant.
6. When a measurement is written in scientific notation, all digits in the coefficient are significant.
7. Counted and defined values have infinite significant digits.

Table 2 shows examples of significant digits.

Table 2 Certainty in Significant Digits

Measurement	Number of significant digits
32.07 m	4
0.0041 g	2
5 × 105 kg	1
7002 N·m	4
6400 s	2
6.0000 A	5
204.0 cm	4
10.0 kJ	3
100 people (counted)	infinite

An answer obtained by multiplying and/or dividing measurements is rounded to the same number of significant digits as the measurement with the fewest significant digits. For example, using a calculator to solve the following equation,

$$77.8 \text{ km/h} \times 0\ 8967 \text{ h} = 69.76326 \text{ km}$$

However, the certainty of the answer is limited to three significant digits, so the answer is rounded up to 69.8 km. The same applies to scientific notation. For example,

$$(5.5 \times 10^4) + (4.236 \times 10^4) = 9.7 \times 10^4$$

ROUNDING

When adding or subtracting measurements of different precisions, the answer is rounded to the same precision as the least precise measurement. For example, using a calculator,

$$11.7 \text{ cm} + 3.29 \text{ cm} + 0\ 542 \text{ cm} = 15.532 \text{ cm}$$

The answer must be rounded to 15.5 cm because the first measurement limits the precision to a tenth of a centimetre.

Follow these rules to round answers to calculations:

1. When the first digit to be dropped is 4 or less, the last digit retained should not be changed.
   3.141 326 rounded to 4 digits is 3.141
2. When the first digit to be dropped is greater than 5, or if it is a 5 followed by at least one digit other than zero, the last digit retained is increased by 1 unit.
   2.221 682 rounded to 5 digits is 2.2217
   4.168 501 rounded to 4 digits is 4.169
3. When the first digit discarded is 5 followed by only zeros, the last digit retained is increased by 1 if it is odd, but not changed if it is even.
   2.35 rounded to 2 digits is 2.4
   2.45 rounded to 2 digits is 2.4
   −6.35 rounded to 2 digits is −6.4

MEASUREMENT ERROR

There are two types of measurement error: random error and systematic error. Random error results when an estimate is made to obtain the last significant digit for any measurement. The size of the random error is determined by the precision of the measuring instrument. For example, when measuring length with a measuring tape, it is necessary to estimate between the marks on the measuring tape. If these marks are 1 cm apart, the random error will be greater and the precision will be less than if the marks are 1 mm apart. Such errors can be reduced by taking the average of several readings.

Systematic error is associated with an inherent problem with the measuring system, such as the presence of an interfering substance, incorrect calibration, or room conditions. For example, if a balance is not zeroed at the beginning, all measurements will have a systematic error; using a slightly worn metre stick will also introduce a systematic error. Such errors are reduced by adding or subtracting the known error, calibrating the instrument, or performing a more complex investigation.

PRECISION AND ACCURACY

Precision and accuracy are two other terms used to describe how close a measurement is to a true value. The precision of a measurement depends upon the gradations of the measuring device. Precision is the place value of the last measurable digit. For example, a measurement of 12.74 cm is more precise than a measurement of 127.4 cm because the first value was measured to hundredths of a centimetre, whereas the latter was measured to tenths of a centimetre.

No matter how precise a measurement is, it still may not be accurate. Accuracy refers to how close a value is to its accepted value. An accurate measurement has a low uncertainty. **Figure 1** shows an analogy between precision and accuracy: the positions of golf balls on a golf course.

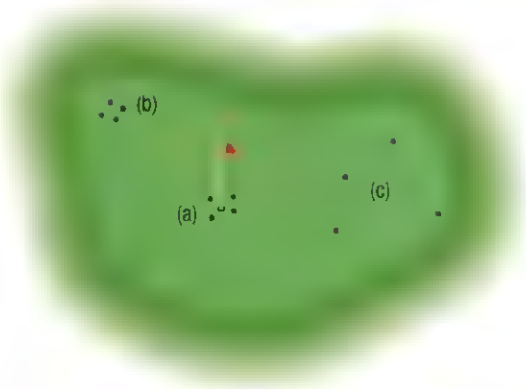


Figure 1 In (a) the results are precise and accurate, in (b) they are precise but not accurate, and in (c) they are neither precise nor accurate.

How certain you are about a measurement depends on two factors: the precision of the instrument used and the size of the measured quantity. More precise instruments give more certain values. For example, a mass measurement of 13 g is less precise than a measurement of 12.76 g; you are more certain about the second measurement than the first. Certainty also depends on the size of the measurement. For example, consider the measurements 0.4 cm and 15.9 cm; both have the same precision. However, if the measuring instrument is precise to ± 0.1 cm, the first measurement is 0.4 ± 0.1 cm (0.3 cm or 0.5 cm) for an error of 25 %, whereas the second measurement could be 15.9 ± 0.1 cm (15.8 cm or 16.0 cm) for an error of 0.6 %. For both factors—the precision of the instrument used and the value of the measured quantity—the more digits there are in a measurement, the more certain you are about the measurement.

REPORTING DATA INVOLVING MEASUREMENTS

A formal report of an experiment involving measurements should include an analysis of uncertainty, percentage uncertainty, and percentage error or percentage difference. Uncertainty is often assumed to be plus or minus half of the smallest division of the scale on the instrument; for example, the estimated uncertainty of 15.8 cm is ± 0.05 cm or ± 0.5 mm.

Whenever calculations involving addition or subtraction are performed, the uncertainties accumulate. Thus, to find the total uncertainty, the individual uncertainties must be added. For example,

$$(34.7\text{ cm} \pm 0.05\text{ cm}) - (18.4\text{ cm} \pm 0.05\text{ cm}) = 16.3\text{ cm} \pm 0.10\text{ cm}$$

Percentage uncertainty is calcuated by dividing the uncertainty by the measured quantity and multiplying by 100. Use your calculator to prove that 28.0 cm ± 0.05 cm has a percentage uncertainty of ± 0.18 %.

Whenever calculations involving multiplication or division are performed, the percentage uncertainties must be added. If desired, the total percentage uncertainty can be converted back to uncertainty. For example, consider the area of a certain rectangle.

$$\begin{aligned} A &= lw \\ &= (28.0\text{ cm} + 0.18\ \%)(21.5\text{ cm} + 0.23\ \%) \\ &= 602\text{ cm}^2 \pm 0.41\ \% \\ A &= 602\text{ cm}^2 \pm 2.5\text{ cm}^2 \end{aligned}$$

Percentage error can be determined only if it is possible to compare a measured value with that of the most commonly accepted value. The equation is

$$\%\text{ error} = \frac{\text{measured value} - \text{accepted value}}{\text{accepted value}} \times 100$$

Percentage difference is useful for comparing two measurements when the true measurement is not known or for comparing a measured value to a predicted value. The percentage difference is calculated as

$$\%\text{ difference} = \frac{\text{measured value} - \text{predicted value}}{\text{predicted value}} \times 100$$

A6.3 Probability

In scientific investigations, probability is a measure of the likelihood of a specific event occurring and is usually expressed as a number between 0 and 1. A probability of 0 means the event will not occur; a probability of 1 means the event will definitely occur. Probabilities may also be expressed as fractions or as percents.

There are two types of probability: theoretical probability and experimental probability. Theoretical probability is the likelihood of an event occurring based on the information known about certain conditions. This is an expectation.

$$\text{theoretical probability} = \frac{\text{number of desired outcomes}}{\text{total number of possible outcomes}}$$

Example 1

Black fur colour is a dominant trait in guinea pigs, while white fur colour is a recessive trait. What is the theoretical probability of a pair of heterozygous black guinea pigs (*Bb*) producing offspring with white fur (*bb*)? Using a Punnett square (**Figure 2**), we show that if four offspring were produced, it is expected that three would have black fur and one would have white fur.

	B	***b***
B	***BB***	***Bb***
b	***Bb***	***bb***

Figure 2 Punnett square showing a *Bb* × *Bb* cross

$$\begin{aligned} \text{theoretical probability} &= \frac{\text{number of desired outcomes}}{\text{total number of possible outcomes}} \\ &= \frac{\text{number of offspring with white fur}}{\text{total number of possible outcomes}} \\ &= \frac{1}{4} \\ &= 0.25 \\ &= 25\ \% \end{aligned}$$

The theoretical probability of producing white offspring is $\frac{1}{4}$ or 25 %. So if a litter had eight offspring, then you could expect two to have white fur. Experimental probability is based on the recorded outcomes or events of an investigation. The more often an experiment is repeated or the more observations made, the closer the experimental probability will be to the theoretical probability.

$$\text{experimental probability} = \frac{\text{number of desired outcomes observed}}{\text{total number of observations}}$$

Example 2

Black fur colour is a dominant trait in guinea pigs, while white fur colour is a recessive trait. Two heterozygous black guinea pigs (*Bb*) were crossed. The litter contained six offspring with black fur and one with white fur. What is the experimental probability of producing offspring with white fur?

$$\text{experimental probability} = \frac{\text{number of desired outcomes observed}}{\text{total number of observations}}$$

$$= \frac{\text{number of offspring with white fur}}{\text{total number of possible offspring}}$$

$$= \frac{1}{7}$$

$$= 0.14$$

$$= 14\ \%$$

The experimental probability of having offspring with white fur is 14 %. If you performed the same analysis on a large number of litters, you would expect the experimental probability to be the same as (or very close to) the theoretical probability.

A6.4 Graphs

There are many types of graphs that you can use to organize your data. You need to identify which type of graph is best for your data before you begin graphing. Three of the most useful kinds are bar graphs, circle (pie) graphs, and point-and-line graphs.

BAR GRAPHS

When at least one of the variables is qualitative, use a bar graph to organize your data (**Figure 3**). For example, a bar graph would be a good way to present the data collected from a study of the number of plants (quantitative) and the type of plants found (qualitative) in a local nursery. In this graph, each bar stands for a different category, in this case a type of plant.

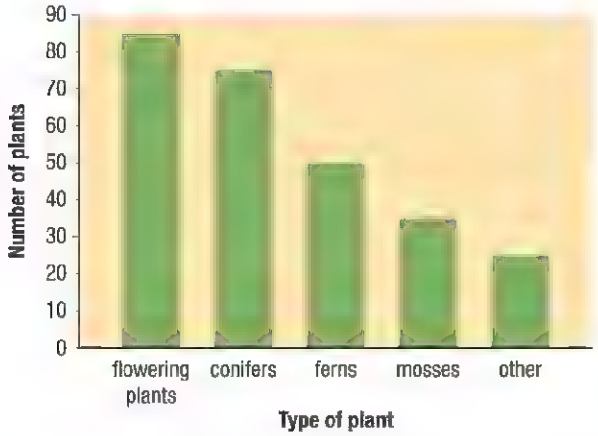


Figure 3 Bar graph

CIRCLE GRAPHS

A circle graph is used if the quantitative variable can be changed to a percentage of a total quantity (**Figure 4**). For example, if you surveyed a local nursery to determine the types of plants found and the number of each, you could make a circle graph. Each piece in the graph stands for a different category (for example, the type of plant). The size of each piece is determined by the percentage of the total that belongs in each category (for example, the percentage of plants of a particular type).

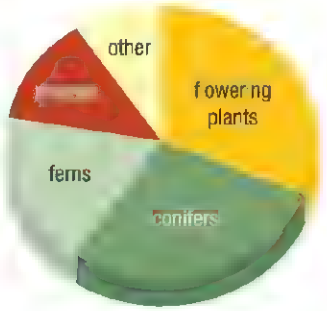


Figure 4 Circle graph

POINT-AND-LINE GRAPHS

When both variables are quantitative, use a point-and-line graph. For example, you can use the following guidelines and the data in **Table 3** to construct point-and-line graph.

Table 3 Number of brine shrimp eggs hatched in salt solutions of various concentrations

Day	2 % salt	4 % salt	6 % salt	8 % salt
1	0	0	0	1
2	0	11	2	3
3	0	14	8	5
4	2	20	17	8
5	5	37	25	15
6	6	51	37	31

1. Use graph paper and construct your graph on a grid. The horizontal edge on the bottom of this grid is the *x*-axis and the vertical edge on the left is the *y*-axis. Do not be too thrifty with graph paper—a larger graph is easier to interpret.
2. Decide which variable goes on which axis and label each axis, including the units of measurement. The independent variable is generally plotted along the *x*-axis and the dependent variable along the *y*-axis.

3. Title your graph. The title should be a concise description of the data contained in the graph.
4. Determine the range of values for each variable. The range is the difference between the largest and smallest values. Graphs often include extra length on each axis, to make them appear less cramped.
5. Choose a scale for each axis. This will depend on how much space you have and the range of values for each axis. Each line on the grid usually increases steadily in value by a convenient number, such as 1, 2, 5, 10, 50, or 100.
6. Plot the points. Start with the first pair of values, which may or may not be at the origin of the graph.
7. After all the points are plotted, draw a line through the points to show the relationship between the variables, if possible. Not all points may lie exactly on a line; small errors in each measurement may have occurred and moved the points away from the perfect line. Draw a line that comes closest to most of the points. This is called the line of best fit—a smooth line that passes through or between the points so that there are about the same number of points on each side of the line. The line of best fit may be straight or curved (**Figure 5**). Graphs often use different colours or symbols to indicate the different sets, and include a legend. In some cases, you may prefer to join the dots when graphing values that are counted rather than measured.

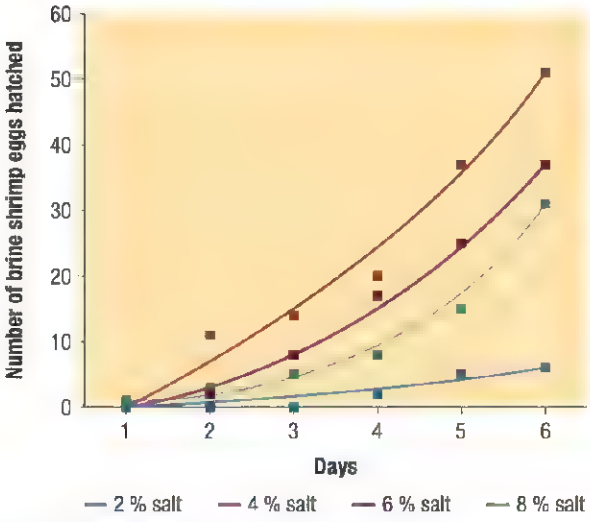


Figure 5 Point-and-line graph

A7 Choosing Appropriate Career Pathways

One of the most difficult tasks in high school is deciding what career path to follow after graduation. The science skills and concepts presented in this book will be of benefit to many careers, whether you are planning a career in scientific research (such as research geneticist or astrophysicist) or in areas related to science (such as environmental lawyer, pharmaceutical sales rep, or electrician). The strong critical-thinking and problem-solving skills that are emphasized in science programs are a valuable asset for any career.

Career Links and Pathways

Throughout this textbook you will have many opportunities to explore careers related to your studies in Biology. The Career Links icons found in the margins indicate that you can learn more about these careers on the Nelson Science website. At the end of each chapter you will also find a Career Pathways feature that illustrates educational pathways for some of the careers mentioned.

It is wise to begin researching academic requirements as early as possible. Understanding the options available to pursue a particular career will help you make decisions on whether to attend university or college, and which program of study you should take. In addition, understanding the terminology used by universities and colleges will play an integral role in planning your future.

University and College Programs

Undergraduate university programs generally lead to a three-year general bachelor degree or a four-year honours bachelor degree. These degree designations begin with a "B" followed by the area of specialization; for example, a B.Sc. (Hons.) indicates an Honours Bachelor of Science degree. These degrees can lead to employment or to further education in Masters or Doctorate postgraduate programs.

College programs typically fall into three categories: one-year certificates, two-year diplomas, and three-year advanced diplomas. Certificates and diplomas can lead directly to employment opportunities or to graduate certificate programs. In some programs, there are "transfer agreements" with universities, which allow college graduates to enter university programs with advanced standing toward a university degree.

Pathways in Biology

The Career Pathways graphic organizer illustrates possible pathways to follow after high school. Certain pathways lead to careers via university while others may lead to careers via college. Look at **Figure 1** below. The pathways of two students are highlighted, both requiring students to complete the Grade 11 and 12 University Biology courses (along with other prerequisites) and initially enter an undergraduate university program.

Student A wishes to become a veterinarian. Since veterinary medicine is a second-entry program, student A must first obtain the necessary university-level prerequisites for veterinary medicine in an undergraduate science program. Student A can then continue to a Doctor of Veterinary Medicine program and ultimately become a veterinarian.

Student B wishes to become a genetic counsellor. Student B must first obtain a Bachelor of Arts degree and then can seek employment as a genetic counsellor.

Planning for Your Future

Planning ahead for your educational and career paths will provide a rewarding future. You should consult your guidance counsellors for specific advice on career planning and which courses you should take in high school. Take the time to research university and college websites for specific program information as these sites will provide the prerequisite information and, most often, career planning advice. While it may seem overwhelming at times, utilizing as many resources as possible will help alleviate some of the stress in planning your future.

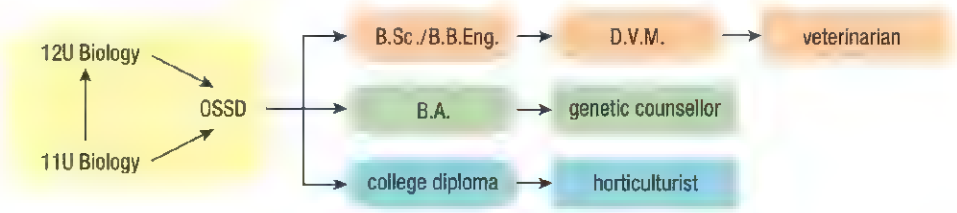


Figure 1 This graphic organizer shows pathways to several careers in biology. The pathway for student A, who wishes to become a veterinarian, is highlighted in orange. The pathway for student B, who wishes to become a genetic counsellor, is highlighted in green.

APPENDIX B REFERENCE

Throughout *Nelson Biology 11* and in this reference section, we have attempted to be consistent in the presentation and usage of units. As far as possible, the text uses the International System of Units (SI). However, some other units have been included because of their practical importance, wide usage, or use in specialized fields.

Nelson Biology 11 has followed the most recent Canadian Metric Practice Guide (CAN/CSA-Z234.1-00), published in 2000 and updated in 2003 by the Canadian Standards Association.

Table 1 SI Base Units

Quantity	Symbol	Unit name	Symbol
amount of substance	*n*	mole	mol
Celsius temperature	*t*	Celsius	°C
length	*L, l, h, d, w*	metre	m
mass	*m*	kilogram	kg
time	*t*	second	s

Table 2 Some SI Derived Units

Quantity	Symbol	Unit	Unit symbol	SI base unit
area	*A*	square metre	m^2	m^2
density	ρ, *D*	kilogram per cubic metre	kg/m^3	kg/m^3
displacement	$\Delta\vec{\delta}$	metre	m	m
energy	E, E_k, E_p	joule	J	$kg \cdot m^2/s^2$
force	*F*	newton	N	$kg \cdot m/s^2$
frequency	*f*	hertz	Hz	s^{-1}
heat	*Q*	joule	J	$kg \cdot m^2/s^2$
pressure	*p*	newton per square metre	N/m^2	$kg/m \cdot s^2$
volume	*V*	cubic metre	m^3	m^3
weight	*W, w*	newton	N	$N, kg \cdot m/s^2$
work	*W*	joule	J	$kg \cdot m^2/s^2$

LEARNING TIP

SI Prefixes

Sometimes it is difficult to remember the metric prefixes. A mnemonic is a saying that helps you remember something. "King Henry Doesn't Mind Drinking Chocolate Milk" is a mnemonic for kilo, hecto, deca, metre, deci, centi, and milli. Another helpful hint is that mega (M) represents a million ($\times 10^6$) and tera (T) represents a trillion ($\times 10^{12}$). The first letters of the prefix and of what it represents are the same. Keep this in mind as you read Table 3.

Table 3 Numerical Prefixes

Powers and Subpowers of Ten		
Prefix	**Power**	**Symbol**
deca	10^1	da
hecto	10^2	h
kilo	10^3	k
mega	10^6	M
giga	10^9	G
tera	10^{12}	T
peta	10^{15}	P
exa	10^{18}	E
deci	10^{-1}	d
centi	10^{-2}	c
milli	10^{-3}	m
micro	10^{-6}	μ
nano	10^{-9}	n
pico	10^{-12}	p
femto	10^{-15}	f
atto	10^{-18}	a

Some Examples of Prefix Use

2000 metres $= 2 \times 10^3$ metres $=$ 2 **kilo**metres or 2 km
0.27 metres $= 27 \times 10^{-2}$ metres $=$ 27 **centi**metres or 27 cm
3 000 000 000 hertz $= 3 \times 10^9$ hertz $=$ 3 **giga**hertz or 3 GHz

Table 4 The Greek Alphabet

A	α	alpha
B	β	beta
Δ	δ	delta
Θ	θ	theta
Λ	λ	lambda
M	μ	mu
Π	π	pi

Table 5 Data for Some Radioisotopes

Atomic number (Z)	Name	Symbol	Atomic mass (u)	Decay type	Half-life
6	carbon-14	$^{14}_{6}C$	14.003 242	β^-	5730 a
8	oxygen-15	$^{15}_{8}O$	15.003 065	β^+	122.24 s
15	phosphorus-32	$^{32}_{16}P$	31.973 908	β	14.262 d
19	potassium-40	$^{40}_{19}K$	39.96 400	β , β^+	1.28×10^9 a
53	iodine-131	$^{131}_{53}I$	130.906 111	β^-, γ	8.04 d
86	radon-222	$^{222}_{86}Rn$	222.017 571	α, γ	3.8235 s

Methods of Cell Membrane Transport

Passive processes

	Vehicle	Substances	Methods	Examples
Diffusion	directly through phospholipid bilayer	hydrophobic and small hydrophilic molecules	random molecular motion causes movement down a concentration gradient	movement of carbon dioxide out of cells
Facilitated Diffusion	passive selective protein carrier	small hydrophilic molecules and ions	carrier protein binds specific molecules and moves them down their own concentration gradient	movement of glucose into cells (**Figure 1**)
Osmosis	directly through phospholipid bilayer	water	water diffuses through membrane down its own concentration gradient	movement of water across a selectively permeable membrane from a hypotonic solution into a hypertonic solution until solutions on both sides of the membrane are isotonic (**Figure 2**)

Active processes

	Vehicle	Substances	Methods	Examples
Endocytosis (Phagocytosis and Pinocytosis)	membrane vesicle	solid particles; extracellular fluid	particles engulfed by pseudopod action; liquid engulfed by pseudopod action	ingestion of bacteria by macrophages in blood; pinocytosis by cells lining small blood vessels (**Figure 3**, next page)
Exocytosis	secretory vesicle	substances formed within the cell	secretory vesicles in the cytoplasm fuse with the cell membrane and spill their contents into the extracellular fluid	secretion of digestive enzymes by cells of the pancreas (**Figure 4**, next page)
Active Transport	active selective protein carrier	ions and small to medium-sized hydrophilic molecules	carrier proteins use cell energy in the form of ATP or electrochemical gradients to transport specific molecules across a membrane	movement of the Na^+ and K^+ ions against concentration gradients across nerve cell membranes (**Figure 5**, next page)

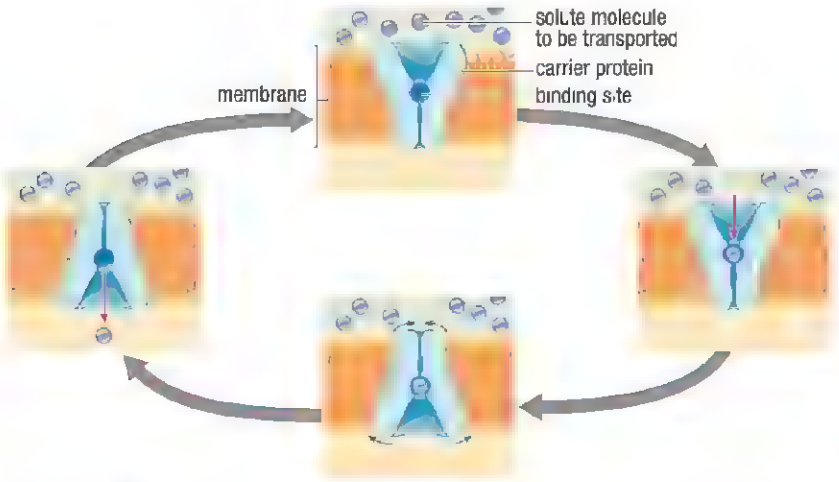


Figure 1 Facilitated diffusion. (a) The carrier protein is folded so that the binding site is exposed toward the region of higher concentration. (b) The carrier protein binds a solute molecule, which causes it to (c) change its folding conformation so that the binding site is exposed to the region of lower concentration. (d) The transported solute is released and the carrier protein returns to its original conformation.

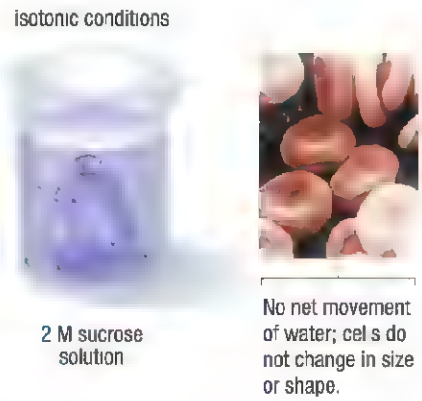


Figure 2 Osmosis

Figure 3 Endocytosis

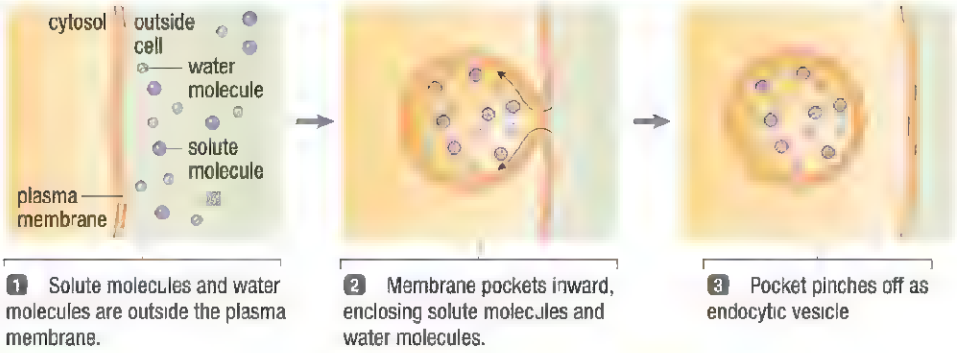


Figure 4 Exocytosis

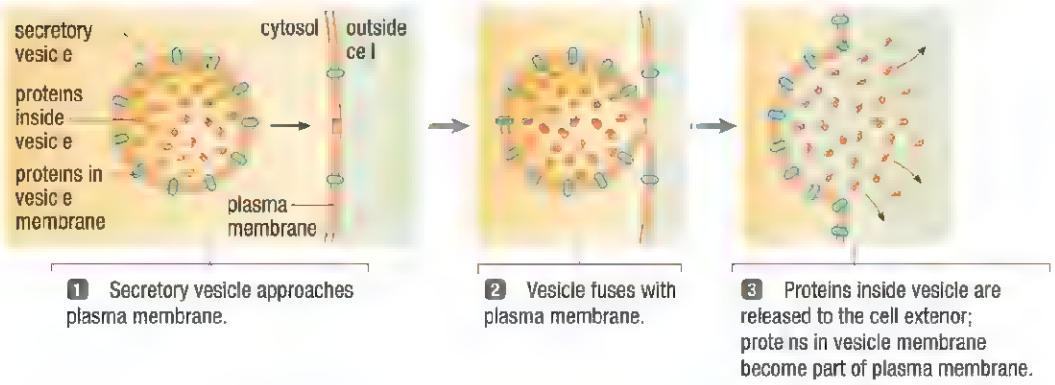
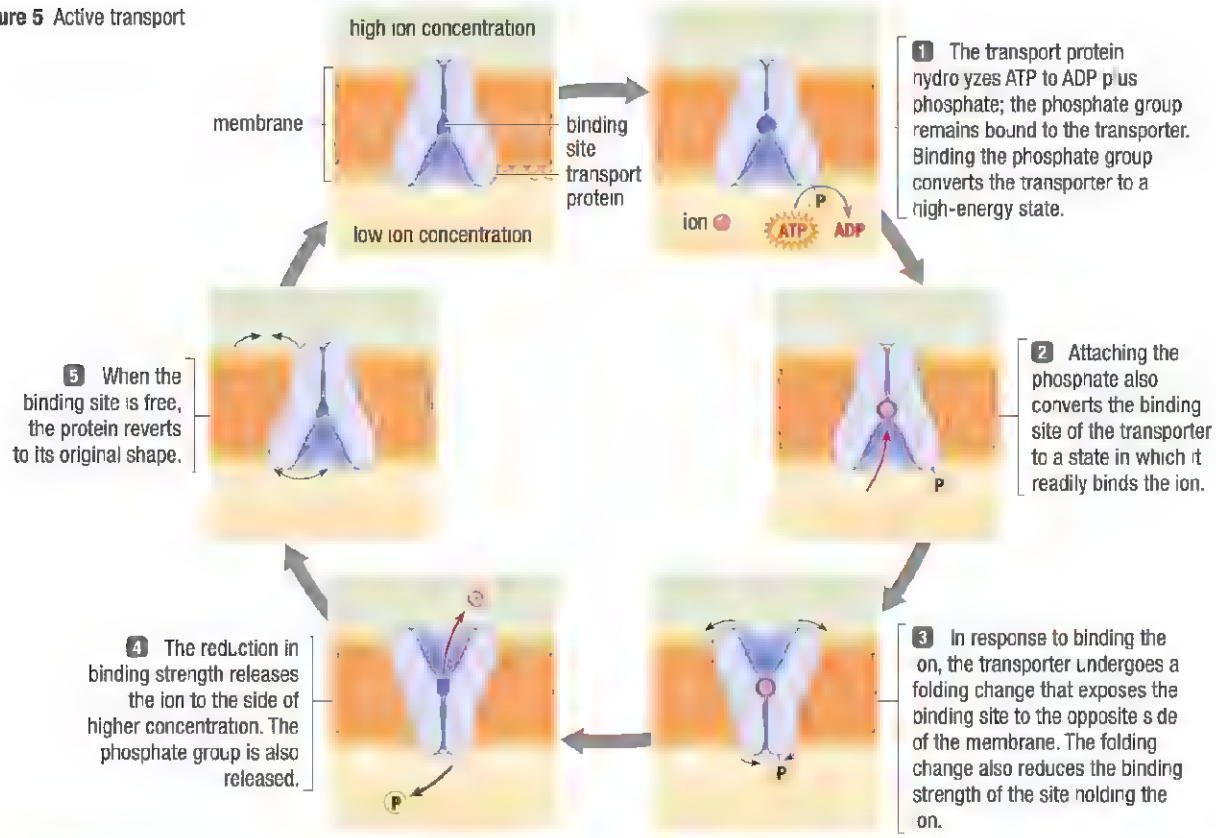
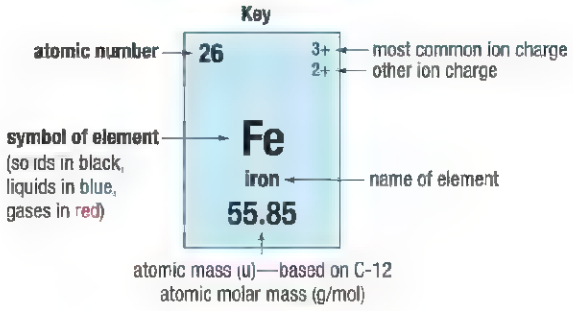


Figure 5 Active transport



Nelson Biology 11



	1	2	3	4	5	6	7	8	9
1	1 1+ 1− **H** hydrogen 1.01								
2	3 1+ **Li** lithium 6.94	4 2+ **Be** beryllium 9.01							
3	11 1+ **Na** sodium 22.99	12 2+ **Mg** magnesium 24.31							
4	19 1+ **K** potassium 39.10	20 2+ **Ca** calcium 40.08	21 3+ **Sc** scandium 44.96	22 4+ 3+ **Ti** titanium 47.87	23 5+ 4+ **V** vanadium 50.94	24 3+ 2+ **Cr** chromium 52.00	25 2+ 4+ **Mn** manganese 54.94	26 3+ 2+ **Fe** iron 55.85	27 2+ 3+ **Co** cobalt 58.93
5	37 1+ **Rb** rubidium 85.47	38 2+ **Sr** strontium 87.62	39 3+ **Y** yttrium 88.91	40 4+ **Zr** zirconium 91.22	41 5+ 3− **Nb** niobium 92.91	42 6+ **Mo** molybdenum 95.96	43 7+ **Tc** technetium (98)	44 3+ 4+ **Ru** ruthenium 101.07	45 3+ **Rh** rhodium 102.91
6	55 1+ **Cs** cesium 132.91	56 2+ **Ba** barium 137.33	57 3+ 2+ **La** lanthanum 138.91	72 4+ **Hf** hafnium 178.49	73 5+ **Ta** tantalum 180.95	74 6+ **W** tungsten 183.84	75 7+ **Re** rhenium 186.21	76 4+ **Os** osmium 190.23	77 4+ **Ir** iridium 192.22
7	87 1+ **Fr** francium (223)	88 2+ **Ra** radium (226)	89 3+ 2+ **Ac** actinium (227)	104 **Rf** rutherfordium (261)	105 **Db** dubnium (262)	106 **Sg** seaborgium (266)	107 **Bh** bohrium (264)	108 **Hs** hassium (277)	109 **Mt** meitnerium (268)

Alkali metals — Alkaline earth metals

6	58 3+ **Ce** cerium 140.12	59 3+ **Pr** praseodymium 140.91	60 3+ **Nd** neodymium 144.24	61 3+ **Pm** promethium (145)	62 3+ 2+ **Sm** samarium 150.36
7	90 4+ **Th** thorium 232.04	91 5+ 4+ **Pa** protactinium 231.04	92 5+ 4+ **U** uranium 238.03	93 6+ **Np** neptunium (237)	94 4+ 6+ **Pu** plutonium (244)

metals
metalloids
non-metals
hydrogen

Periodic Table of the Elements

Measured values are subject to change as experimental techniques improve.

Atomic molar mass values in this table are based on IUPAC website values (2005 and 2007).

10	11	12	13	14	15	16	17	18	
								2 — **He** helium 4.00	1
			5 — **B** boron 10.81	6 — **C** carbon 12.01	7 3− **N** nitrogen 14.01	8 2− **O** oxygen 16.00	9 1− **F** fluorine 19.00	10 — **Ne** neon 20.18	2
			13 3+ **Al** aluminum 26.98	14 **Si** silicon 28.09	15 3− **P** phosphorus 30.97	16 2− **S** sulfur 32.07	17 1− **Cl** chlorine 35.45	18 — **Ar** argon 39.95	3
28 2+ 3+ **Ni** nickel 58.69	29 2+ 1+ **Cu** copper 63.55	30 2+ **Zn** zinc 65.41	31 3+ **Ga** gallium 69.72	32 4+ **Ge** germanium 72.64	33 3− **As** arsenic 74.92	34 2− **Se** selenium 78.96	35 1− **Br** bromine 79.90	36 — **Kr** krypton 83.80	4
46 2+ 3+ **Pd** palladium 106.42	47 1+ **Ag** silver 107.87	48 2+ **Cd** cadmium 112.41	49 3+ **In** indium 114.82	50 4+ 2+ **Sn** tin 118.71	51 3+ 5+ **Sb** antimony 121.76	52 2− **Te** tellurium 127.60	53 1− **I** iodine 126.90	54 — **Xe** xenon 131.29	5
78 4+ 2+ **Pt** platinum 195.08	79 3+ 1+ **Au** gold 196.97	80 2+ 1+ **Hg** mercury 200.59	81 1+ 3+ **Tl** thallium 204.38	82 2+ 4+ **Pb** lead 207.2	83 3+ 5+ **Bi** bismuth 208.98	84 2+ 4+ **Po** polonium (209)	85 1− **At** astatine (210)	86 — **Rn** radon (222)	6
110 **Ds** darmstadtium (281)	111 **Rg** roentgenium (272)	112 **Cn** copernicium (285)	113 **Uut** ununtrium (284)	114 **Uuq** ununquadium (289)	115 **Uup** ununpentium (288)	116 **Uuh** ununhexium (291)	117 **Uus** ununseptium	118 **Uuo** ununoctium (294)	7
							Halogens	Noble gases	
63 3+ 2+ **Eu** europium 151.96	64 3+ **Gd** gadolinium 157.25	65 3+ **Tb** terbium 158.93	66 3+ **Dy** dysprosium 162.50	67 3+ **Ho** holmium 164.93	68 3+ **Er** erbium 167.26	69 3+ **Tm** thulium 168.93	70 3+ 2+ **Yb** ytterbium 173.05	71 2+ **Lu** lutetium 174.97	6
95 3+ 4+ **Am** americium (243)	96 3+ **Cm** curium (247)	97 3+ 4+ **Bk** berkelium (247)	98 3+ **Cf** californium (251)	99 3+ **Es** einsteinium (252)	100 3+ **Fm** fermium (257)	101 2+ 3+ **Md** mendelevium (258)	102 2+ 3+ **No** nobelium (259)	103 3+ **Lr** lawrencium (262)	7

APPENDIX C ANSWERS

These pages include numerical and short answers to chapter section questions and Chapter Self-Quiz, Chapter Review, Unit Self-Quiz, and Unit Review questions.

Unit 1

Are You Ready? p. 4

2. (a) F
   (b) T
   (c) F
   (d) F
   (e) F
3. (a) iii
   (b) i
   (c) ii
   (d) iv
15 (a) iii
   (b) iv
   (c) i
   (d) ii

1.4 Questions, p. 29

3. (b) fungi, animals

1.5 Questions, p. 31

1. (a) birds

Chapter 1 Self-Quiz, p. 37

1. c	8. b	15. F
2. a	9. d	16. F
3. b	10. F	17. T
4. b	11. T	18. F
5. c	12. T	19. T
6. d	13. F	20. F
7. a	14. T	21. T

Chapter 1 Review, p. 38

1. d
2. a
3. d
4. d
5. c
6. c
7. c
8. b
9. b
10. (a) i
    (b) ii
    (c) iii
    (d) iii
    (e) iii
    (f) iii
11. F
12. T
13. F
14. T
15. F
16. F
17. T
56. (a) vii
    (b) i
    (c) iv
    (d) iii
    (e) vi
    (f) v
    (g) viii
    (h) ii

Chapter 2 Self-Quiz, p. 71

1. d	8. c	15. T
2. a	9. a	16. T
3. a	10. b	17. T
4. d	11. F	18. T
5. d	12. T	19. T
6. b	13. F	20. F
7. c	14. F	

Chapter 2 Review, p. 72

1. c
2. b
3. b
4. c
5. a
6. c
7. d
8. (a) iii
   (b) ii
   (c) iv
   (d) i
   (e) v
9. F
10. F
11. F
12. F
13. T
14. T
15. T
16. F
17. F
18. F
19. T
20. T
21. F
43. (a) (i) cel. wall
    (ii) flagellum
    (iii) cytoplasm
    (iv) condensed DNA molecule
    (v) pili
    (vi) plasm.d
    (b) (i) head
    (ii) capsid
    (iii) viral DNA
    (iv) sheath
    (v) tail
61. (a) 4000

Chapter 3 Self-Quiz, p. 113

1. b	8. b	15. F
2. c	9. a	16. F
3. d	10. d	17. T
4. d	11. T	18. F
5. a	12. F	19. F
6. b	13. F	20. F
7. a	14. T	21. T

Chapter 3 Review, p. 114

1. c
2. b
3. c
4. a
5. c
6. d
7. b
8. (a) i
   (b) v
   (c) ii
   (d) vi
   (e) iii
   (f) iv
9. F
10. T
11. F
12. F
13. F
14. F
15. T
16. T
17. F
18. T
19. F
20. T
21. F
22. T

Unit 1 Self-Quiz, p. 122

1. b	14. a	27. T
2. d	15. d	28. T
3. d	16. d	29. F
4. b	17. c	30. F
5. a	18. c	31. T
6. a	19. F	32. T
7. b	20. T	33. T
8. a	21. T	34. F
9. b	22. T	35. T
10. d	23. F	36. F
11. c	24. T	37. F
12. d	25. F	38. T
13. b	26. F	39. T

Unit 1 Review, p. 124

1. d
2. a
3. c
4. b
5. d
6. c
7. c
8. d
9. b
10. a
11. a
12. b
13. T
14. F
15. F
16. T
17. T
18. F
19. T
20. F
21. F
22. T
23. T
24. F

Unit 2

Are You Ready? p. 134

1. (a) v
   (b) vi
   (c) iv
   (d) i
   (e) ii
   (f) iii
2. (a) chloroplast
   (b) cell wall
   (c) vacuole
   (d) cell membrane
   (e) cytoplasm
   (f) endoplasmic reticulum
   (g) nucleus
   (h) nuclear membrane
   (i) mitochondrion
   (j) Golgi body
20. (a) 50:1
   (b) 3:1
   (c) 1:3
   (d) 1:3.2

4.3 Questions, p. 160

8. telophase I
9. 1024

4.4 Questions, p. 166

9. (a) male

Ch 4 Self-Quiz, p. 175

1. c	8. c	15. T
2. c	9. d	16. F
3. b	10. F	17. F
4. d	11. T	18. T
5. c	12. T	19. F
6. a	13. F	20. F
7. a	14. F	

Chapter 4 Review, p. 176

1. a
2. a
3. c
4. c
5. b
6. c
7. d
8. c
9. a
10. T
11. T
12. F
13. T
14. F
15. F
16. T
17. T
18. T

19. (a) ii
(b) i
(c) v
(d) iii
(e) iv
20. (a) iv
(b) iii
(c) i
(d) ii
21. polyploid
22. 6
29. homologous
34. artificial insemination
37. horizontal gene transfer
44. (a) 23
61. (a) 7
(b) 1
(c) 6
63. (a) XY
(b) XX
64. (a) female

5.1 Questions, p. 193

8. (a) 1:1 genotypic ratio *Ss* : *ss*
(b) 1:1 phenotypic ratio
1 smooth : 1 wrinkled
(c) 25
10. (a) heterozygous (*Rr*)
(b) 1:1

5.2 Questions, p. 196

2. (a) F^BF^B
(b) F^WF^W
(c) F^BF^W
6 I^AI^A, I^Ai
7. father I^Ai and mother I^Bi

5.3 Questions, p. 201

5. (a) Y linked

5.7 Questions, p. 214

2. (a) *We*, *we*
(b) *Ea*, *ea*
(c) *tY*
3. (c) 2/8 = 25%
4. (b) Stud *BoTt*, Mare 1 *BbTt* or *BBTt*, Colt 1 *BBtt* or *Bbtt*, Mare 2 *bbtt*, Colt 2 *bbTT*

Chapter 5 Self-Quiz, p. 219

1. a	9. a	17. F
2. a	10. F	18. T
3. c	11. T	19. F
4. a	12. T	20. T
5. b	13. T	21. F
6. b	14. T	22. F
7. d	15. F	23. T
8. d	16. F	24. F

Chapter 5 Review, p. 220

1. a
2. c
3. b
4. c
5. a
6. a
7. a
8. c
9. (a) iii
(b) v
(c) ii
(d) i
(e) iv
10. T
11. F
12. F
13. T
14. T
15. F
16. F
17. T
18. T
20. 4.0
23. *HH*, *Hh*, *hh*
24. 0 %
27. 50 %
28. 9
39. (a) 1:2:1
(b) 1:2:1
(c) 25 %
(d) 50 %
42. (a) 5
(b) 0
(c) 2
51. (a) *Ii*, *II*
(b) *ii*
(c) *ii*, *ii*

6.1 Questions, p. 233

4. AACTGTCATTTT

6.3 Questions, p. 244

8. suspect 2

Chapter 6 Self-Quiz, p. 257

1. b	8. a	15. T
2. c	9. T	16. F
3. d	10. F	17. T
4. d	11. F	18. F
5. b	12. F	19. T
6. c	13. T	
7. a	14. F	

Chapter 6 Review, p. 258

1. b
2. a
3. d
4. b
5. b
6. c
7. d
8. a
9. a
10. F
11. F
12. F
13. T
14. F
15. T
16. F
17. F
18. (a) vi
(b) v
(c) iv
(d) ii
(e) i
(f) iii
19. (a) iii
(b) iv
(c) vi
(d) v
(e) i
(f) ii
20. nucleotides
22. functional genomics
23. freshwater amoeba
24. recombinant
25. mutation
29. (a) deletion
(b) insertion
(c) substitution
53. (a) TACTGCCAGTATGA
TGTATACACGTGCCAG
TATGTATACACT
ATGACGGTCATAC
TACATATGTGCACGG
TCATACATATGTGA

Unit 2 Self-Quiz, p. 266

1. c	14. d	27. T
2. c	15. b	28. T
3. d	16. d	29. F
4. c	17. a	30. T
5. c	18. b	31. F
6. a	19. d	32. F
7. c	20. c	33. F
8. d	21. F	34. T
9. a	22. F	35. F
10. d	23. F	36. F
11. a	24. T	37. T
12. b	25. T	38. F
13. d	26. T	

Unit 2 Review, p. 268

1. a
2. d
3. c
4. c
5. b
6. d
7. a
8. c
9. a
10. (a) iv
(b) ii
(c) iii
(d) i
11. (a) iii
(b) i
(c) ii
12. DNA
13. prophase I
16. grey
26. T
27. F
28. F
29. T
30. F
31. T
54. (a) sex chromosomes
(b) X-linked

Unit 3

Are You Ready? p. 278

18. (a) 40 m
(b) 1775 MY
19. (a) 30 20
(b) 44.12
21. (a) 32 A, 8 B
(b) 16 A; 24 B
(c) 28 A; 12 B

Chapter 7 Self-Quiz, p. 317

1. d	7. b	13. T
2. b	8. a	14. T
3. b	9. T	15. F
4. c	10. F	16. F
5. d	11. F	17. T
6. a	12. T	18. F

Chapter 7 Review, p. 318

1. b
2. a
3. b
4. b
5. d
6. c
7. c
8. a
9. b
10. d
11. c
12. a
13. (a) iii
(b) i
(c) ii
(d) iv
14 (a) iv
(b) i
(c) ii
(d) iii
15. (a) ii, v
(b) i, iii, iv
19. F
20. F
21. F
22. T
23. F
24 T
25. F
26. F
27. F
33. (a) F
(b) T
(c) F
(d) T
34. (a) South America
(b) single species
(c) no
(d) no
35. (a) T
(b) T
(c) F
(d) T
58. (a) homologous

8.2 Questions, p. 340

6. (a) $2n = 22$

8.5 Questions, p. 355

8. (b) D, E
   (c) 1, 2
   (d) D, E
   (e) E
   (f) 3, and only one of 4 or 5

Chapter 8 Self-Quiz, p. 371

1. d	8. b	15. T
2. b	9. F	16. T
3. a	10. F	17. F
4. d	11. T	18. F
5. d	12. T	19. T
6. b	13. T	
7. d	14. F	

Chapter 8 Review, p. 372

1. c
2. b
3. d
4. a
5. b
6. c
7. b
8. d
9. T
10. F
11. T
12. F
13. F
14. T
15. T
16. F

Unit 3 Self-Quiz, p. 380

1. d	14. b	27. F
2. c	15. c	28. T
3. d	16. a	29. F
4. a	17. b	30. T
5. a	18. a	31. T
6. c	19. b	32. F
7. c	20. b	33. T
8. b	21. d	34. F
9. b	22. T	35. F
10. d	23. F	36. F
11. d	24. F	37. F
12. c	25. T	
13. a	26. F	

Unit 3 Review, p. 382

1. a
2. b
3. a
4. d
5. d
6. b
7. a
8. b
9. a
10. F
11. F
12. T
13. T
14. T
15. F
16. F
17. F
18. T
19. F
20. T
21. T
22. F
23. T
24. F
25. F
26. F
27. T
28. T
29. F
30. F
31. (a) i
    (b) iv
    (c) iii
    (d) ii
32. (a) ii
    (b) i
    (c) iv
    (d) iii
33. (a) iv
    (b) iii
    (c) ii
    (d) v
    (e) i
34. (a) iii
    (b) iv
    (c) i
    (d) v
    (e) ii
35. (a) iii
    (b) ii
    (c) i
36. (a) ii
    (b) i
    (c) iii

Unit 4

Are You Ready? p. 392

1. (a) iv
   (b) i
   (c) ii
   (d) iii
5. (a) liver
   (b) small intestine
   (c) large intestine
   (d) esophagus
   (e) stomach
   (f) pancreas
6. (a) i
   (b) ii
   (c) ii
   (d) iii
   (e) i
   (f) iii
   (g) ii
7. c
12. b
13. b
14. a
15. b
16. d
17. c

9.1 Questions, p. 399

4. (a) 3.968 h

Chapter 9 Self-Quiz, p. 429

1. c	8. b	15. T
2. a	9. a	16. T
3. c	10. T	17. F
4. b	11. F	18. F
5. d	12. F	19. T
6. a	13. F	
7. d	14. F	

Chapter 9 Review, p. 430

1. d
2. b
3. a
4. c
5. a
6. b
7. c
8. d
9. F
10. T
11. T
12. T
13. F
14. T
15. F
30. 4693

Chapter 10 Self-Quiz, p. 469

1. d	8. b	15. F
2. c	9. d	16. T
3. b	10. T	17. F
4. c	11. T	18. T
5. a	12. F	19. F
6. b	13. F	
7. a	14. F	

Chapter 10 Review, p. 470

1. a
2. d
3. b
4. a
5. d
6. b
7. c
8. d
9. F
10. F
11. T
12. T
13. F
14. F
15. (a) ii
    (b) iv
    (c) i
    (d) iii
16. (a) iv
    (b) i
    (c) iii
    (d) ii
18. (a) mouth
    (b) pleural membranes
    (c) intercostal muscles
    (d) diaphragm
    (e) nasal passages
    (f) glottis
    (g) lung
    (h) bronchi
20. 8.36 kPa
21. (a) A
    (b) B
22. chemical receptors
24. 36.1
25. phosphorylation
29. (a) erythropoietin (EPO)

Chapter 11 Self-Quiz, p. 517

1. b	7. d	13. T
2. a	8. b	14. F
3. d	9. b	15. T
4. c	10. d	16. F
5. b	11. F	17. T
6. a	12. F	

Chapter 11 Review, p. 518

1. c
2. a
3. b
4. d
5. (a) iii
   (b) v
   (c) iv
   (d) ii
   (e) i
6. (a) iii
   (b) iv
   (c) i
   (d) ii
7. (a) vii
   (b) iii
   (c) v
   (d) i
   (e) ii
   (f) iv
   (g) viii
   (h) vi
8. F
9. T
10. T
11. F
12. F
13. T
14. F
16. Na and Cl
17. white blood cells
19. blood volume
20. (a) superior vena cava
    (b) right atrium
    (c) semilunar valve
    (d) inferior vena cava

(e) right ventricle
(f) aorta
(g) left atrium
(h) left ventricle
(i) atrioventricular valve
(j) septum
44. (a) atrium
(b) ventricles
(c) relax
(d) bicuspid/tricuspid
(e) semilunar
71. (a) 65 bpm
(b) 2 min, 3 min, 5 min, 10 min, 12 min
(c) 12 min
(d) 73 bpm
(e) 4 min

Unit 4 Self-Quiz, p. 526

1. b	13. d	25. F
2. b	14. c	26. F
3. d	15. a	27. T
4. d	16. a	28. F
5. c	17. c	29. F
6. d	18. c	30. T
7. c	19. b	31. T
8. c	20. c	32. F
9. b	21. F	33. F
10. b	22. F	34. T
11. d	23. F	35. T
12. a	24. T	36. F

Unit 4 Review, p. 528

1. c
2. a
3. d
4. b
5. b
6. c
7. d
8. b
9. T
10. F
11. F
12. F
13. T
14. F
15. F
16. T
17. F
18. T
19. F
20. F
21. (a) iii
(b) iv
(c) i
(d) ii
22. (a) iv
(b) iii
(c) ii
(d) i
23. (a) rabbit
28. (a) unsaturated
29. omega-3 fatty acids
31. (a) proteins
(b) carbohydrates
(c) fats
33. (a) duodenum
(b) ileum
(c) individual amino acids
34. (a) transverse colon
(b) ascending colon
(c) cecum
(d) appendix
(e) small intestine
(f) descending colon
(g) sigmoid colon
(h) rectum
(i) internal anal sphincter
(j) external anal sphincter
(k) anus
59. (a) 4200 kJ
(b) 1000 Calories
98. (a) 5453.2 kJ
(b) 7498.3 kJ
(c) 345 Calories
101. (a) 1140 g
(b) lipids

Unit 5

Are You Ready? p. 538

1. (a) vi
(b) iii
(c) iv
(d) v
(e) vii
(f) viii
(g) i
(h) ii
7. (a) apical meristem
(b) flower
(c) leaf
(d) fruit
(e) root
(f) root system
(g) shoot system
(h) vascular tissue
(i) dermal tissue

Chapter 12 Self-Quiz, p. 579

1. a	9. b	17. F
2. d	10. a	18. F
3. c	11. T	19. F
4. d	12. T	20. T
5. b	13. F	21. T
6. b	14. T	22. F
7. d	15. T	23. T
8. d	16. F	24. F

Chapter 12 Review, p. 580

1. c
2. a
3. b
4. d
5. a
6. d
7. c
8. d
9. F
10. F
11. F
12. T
13. T
14. F
15. F

Chapter 13 Self-Quiz, p. 623

1. c	8. a	15. T
2. d	9. b	16. T
3. a	10. F	17. F
4. a	11. T	18. T
5. d	12. T	19. F
6. b	13. F	
7. d	14. F	

Chapter 13 Review, p. 624

1. a
2. d
3. c
4. b
5. b
6. a
7. d
8. T
9. T
10. F
11. F
12. T
13. F
14. T
15. (a) ii
(b) v
(c) iii
(d) vi
(e) iv
(f) i

Unit 5 Self-Quiz, p. 632

1. d	17. d	33. F
2. a	18. d	34. T
3. c	19. a	35. T
4. b	20. c	36. T
5. c	21. c	37. F
6. b	22. c	38. F
7. c	23. d	39. T
8. a	24. b	40. T
9. b	25. T	41. F
10. a	26. T	42. F
11. a	27. F	43. F
12. a	28. F	44. T
13. c	29. F	45. F
14. a	30. T	46. T
15. b	31. F	47. T
16. a	32. F	48. F

Unit 5 Review, p. 634

1. c
2. a
3. c
4. d
5. c
6. c
7. b
8. a
9. a
10. d
11. d
12. d
13. d
14. d
15. (a) ii
(b) iv
(c) iii
(d) i
(e) v
16. (a) ii
(b) i
(c) iv
(d) iii
17. T
18. F
19. T
20. F
21. F
22. T
23. F
24. F
25. T
26. T
27. T
28. T

Glossary

A

abiogenesis the origin of life from non-living matter

active transport the transportation of materials through a cell membrane using energy from the cell

adaptation a characteristic or feature of a species that makes it well suited for survival or reproductive success in its environment

adaptive radiation the relatively rapid evolution of a single species into many new species, filling a variety of formerly empty ecological niches

additive allele an allele that has a partial influence on a phenotype

adventitious root a root that develops from somewhere other than the root apical meristem that emerges from the seed

aerenchyma tissue composed of loosely packed parenchyma cells with large pores; found in aquatic plants

aerobic cellular respiration the series of chemical reactions that occur in the cell that provide energy and consume oxygen

allele a specific form of a gene

allopatric speciation the formation of a new species as a result of evolutionary changes following a period of geographic isolation

alternation of generations a life cycle in which diploid individuals produce spores that create haploid individuals; the haploid individuals reproduce sexually, producing sporophyte individuals and completing the cycle

alveolus a tiny sac at the end of a bronchiole that forms the respiratory membrane

amniotic egg an egg with an outer leathery or hard shell and specialized internal membranes that protect and nourish the embryo

amylase an enzyme that breaks down complex carbohydrates

anabolism the metabolic reactions that use energy to produce larger molecules from smaller subunits

analogous feature a structure that performs the same function as another but is not similar in origin or anatomical structure; for example, bird and insect wings

anemia a condition of a low erythrocyte count or a low hemoglobin level, which leads to low oxygen levels

angina pain in the chest, left shoulder, arm, or neck caused by insufficient blood supply to the cardiac muscles

angiogram an X-ray image showing the outline of blood vessels through the use of an injected dye

angioplasty a medical procedure that opens up a blocked artery; it is often used to enlarge narrowed openings in coronary arteries

angiosperm a plant that produces flowers; angiosperms form the largest group of living plants

anther the floral organ that produces pollen

antheridium the specialized structure on a gametophyte that produces sperm

anthropoid the group of primates that includes monkeys, apes, and humans

antibiotic a substance that can kill or weaken micro-organisms; natural antibiotics are produced by bacteria or fungi, whereas synthetic antibiotics are manufactured

antibiotic resistant describes strains of bacteria that are no longer susceptible to the effects of antibiotics; are sometimes called "superbugs" and are prevalent in hospital settings

anus the opening at the lower end of the large intestine through which digestive wastes are eliminated from the body

aorta the largest blood vessel in the body, connected directly to the heart; the aorta branches into arteries that carry oxygenated blood to the body tissues

apical dominance the condition in which most shoot growth arises from the apical bud and not lateral buds

apical meristem plant tissue composed of actively dividing cells; responsible for primary growth and located at the tip of the root(s) and shoot(s) of a plant

archegonium the specialized structure on a gametophyte that produces eggs

arteriole the smallest artery, with smooth muscle in its walls

arteriosclerosis the loss of elasticity and hardening of the arteries that may be caused by a number of factors including hypertension, age, and plaque buildup

artificial selection directed breeding in which individuals that exhibit a particular trait are chosen as parents of the next generation; artificial selection is used to produce new breeds or varieties of plants and animals

asexual reproduction the production of offspring from a single parent; the genetic makeup of the offspring is identical to that of the parent

asthma a chronic respiratory disease characterized by inflammation and swelling of the bronchi and bronchioles that obstructs airflow

atherosclerosis the hardening of the arteries due to the buildup of plaque on or inside the walls of the arteries; atherosclerosis is the most common form of arteriosclerosis

atrioventricular (AV) node a mass of conducting cells that transmits the signals from the sinoatrial (SA) node to the muscles of the ventricles

atrioventricular valve the valve located between each atrium and ventricle to prevent the backflow of blood from the ventricles to the atria

atrium a chamber of the heart that receives blood from the body

autosomal inheritance inheritance of alleles located on autosomal (non-sex) chromosomes

autosomes non-sex chromosomes

autotroph an organism that uses sources of energy to produce nutrients from water, gases, and/or minerals

B

bacillus a rod-shaped bacterial cell

bacteriophage a virus that infects bacteria

bark the protective outermost layer of the stems and roots of woody plants; consists of phloem, cork cambium, and cork

basal metabolic rate the minimum amount of energy required to keep you alive

beneficial mutation any mutation that increases the reproductive success of an organism; beneficial mutations are favoured by natural selection and accumulate over time

bilateral symmetry symmetry around a midline

bile a substance that emulsifies fats for faster breakdown by lipases; produced by the liver

binary fission the division of one parent cell into two genetically identical daughter cells; a form of asexual reproduction

binomial nomenclature the formal system of naming species whereby each species is assigned a *genus* name followed by a *specific* name; the two words taken together form the species name

biodiversity the number and variety of species and ecosystems on Earth

biogeography the scientific study of the geographic distribution of organisms based on both living species and fossils

biological classification the systematic grouping of organisms into biological categories based on physical and evolutionary relationships

biotechnology the use and modification of organisms for applications in engineering, industry, and medicine

blade the flat part of a leaf

botanist a scientist specializing in the study of plants; also called a plant biologist

bronchial thermoplasty a procedure that decreases the amount of constriction of the airways during an asthma attack by using thermal energy to reduce the muscle thickness in the bronchioles

bronchiole a tiny branch of a bronchus that connects to a cluster of alveoli

bronchus one of the two main branches of the trachea that lead toward the lungs

bryophyte a small seedless plant that lacks vascular tissue

bypass surgery a surgical procedure in which arteries are grafted to blocked (or narrowed) coronary arteries in order to reroute blood flow and oxygen to the heart

C

Cambrian explosion the rapid evolution of most major animal phyla that took place over approximately 40 million years during the Cambrian period

capillary action the tendency of a liquid to rise or fall because of attractive forces between the liquid molecules

capsid a protein coat that surrounds the DNA or RNA of a virus

capsule an outer layer on some bacteria; provides some protection for the cell

carbohydrate a molecule that contains only atoms of carbon, hydrogen, and oxygen in a ratio of 1:2:1

cardiac catheterization the insertion of a long thin tube called a catheter into the heart through an artery, usually the femoral or brachial artery

cardiac cycle the contractions and relaxations of the heart muscles during a complete heartbeat

carpel the female reproductive floral part, comprising a stigma, a style, an ovary, and an ovule

carrier testing a genetic test that determines whether an individual is heterozygous for a given gene that results in a genetic disorder

Casparian strip the wax-like strip that runs through the cell wall of an endodermal cell

catabolism the metabolic reactions that break down larger molecules into smaller subunits

catastrophism the theory that the pattern of fossils could be accounted for by a series of global catastrophes that wiped out most species on Earth

cecum a blind pouch at the upper end of the large intestine

charophyte the common name for organisms in the order Charophyceae; green algae in the kingdom Protista

chitin a complex chemical found in the cell walls of fungi and in the external coverings of insects and crustaceans such as lobsters and crabs

chloroplast an organelle found in large numbers in many plant cells; the site of photosynthesis within a plant cell

chordae tendineae tendons that support the atrioventricular valves

chromatin the tangled strands of DNA and protein within a eukaryotic nucleus

chromosome mutation an error that involves an entire chromosome or a large part of a chromosome

chronic obstructive pulmonary disease (COPD) a chronic, progressive disease that involves both obstructive bronchitis and emphysema

chyme a semi-liquid mixture of food and gastric juice

clade a taxonomic group that includes a single common ancestor and all its descendants

cladistics a method of determining evolutionary relationships based on the presence or absence of recently evolved traits

cloning the process of producing one individual that is genetically identical to another, using a single cell or tissue

coccus a round bacterial cell

coding DNA a region of DNA that contains a sequence of nucleotides that will be expressed; a gene

codominance a situation where both alleles are expressed fully to produce offspring with a third phenotype

coelom a body cavity present in some animals; contains the animal's internal organs

coevolution a process in which one species evolves in response to the evolution of another species

colon the longest part of the large intestine

companion cell a small, nucleated phloem cell that is always associated with a sieve tube element

complementary base pairing pairing of the nitrogenous base of one strand of DNA with the nitrogenous base of another strand; adenine (A) pairs with thymine (T), and guanine (G) pairs with cytosine (C)

complete dominance a situation where an allele will determine the phenotype, regardless of the presence of another allele

computerized tomography (CT) scan an X-ray imaging technology that produces cross-sectional images of a three-dimensional object

concentration gradient the difference in the number of molecules or ions of a substance in a given volume between adjoining areas

cone in plants, the reproductive structure of a conifer; produce either pollen or ovules

conjugation a form of sexual reproduction in which two cells join to exchange genetic information

continuous variation when the product of one gene is affected by the product of another gene, the gene products may be additive, or one product may negate another product

convergent evolution the evolution of similar traits in distantly related species

cork cambium the meristematic layer in a woody plant that produces cork

coronary artery disease (CAD) the buildup of plaque on or inside the walls of the coronary arteries

coronary blood vessel a blood vessel that circulates blood to and from the muscle cells of the heart

cotyledon a structure in the seeds of flowering plants (angiosperm) that stores and supplies nutrients to the embryo

cross the successful mating of two organisms from distinct genetic lines

crossing over the exchange of chromosome segments between homologous pairs during synapsis

cross-pollination the transfer of pollen grains from one plant to another

cuticle a waterproof, waxy coating produced by the epidermis of most plants

cytokinesis the process in which a eukaryotic cell divides its cytoplasm into two new daughter cells

D

deoxyribonucleic acid (DNA) a molecule that carries genetic information in cells

derived trait a trait that has evolved relatively recently with respect to the species or groups being discussed

deuterostome an animal with bilateral symmetry; during embryonic development, the anus forms before the mouth

diaphragm a large sheet of muscle located beneath the lungs that is the primary muscle in breathing

diarrhea loose or watery feces

diastole the period of the cardiac cycle when the ventricles are relaxed; blood fills the ventricles

diastolic pressure the blood pressure in the arteries when the heart relaxes

dichotomous key a series of branching, two-part statements used to identify organisms (or objects)

differentiation the process of cell specialization

dihybrid cross a cross that involves two genes, each consisting of heterozygous alleles

dikaryotic containing two separate nuclei

diploid a cell containing two copies of each chromosome ($2n$)

directional selection selection that favours an increase or decrease in the value of a trait from the current population average

discontinous variation when the expression of the products of one gene has no bearing on the expression of the products of a second gene

disruptive selection selection that favours two or more variations of a trait that differ from the current population average

divergent evolution the large-scale evolution of a group into many different forms

DNA bank a database of DNA sequences; the sequences can be from plants, animals, or humans

DNA fingerprinting a pattern of bands on a gel that is unique to each individual

domain the highest taxonomic level; there are three domains of life

dominant allele the allele that, if present, is always expressed

Down syndrome a chromosomal abnormality in which an individual has three copies of chromosome number 21; also referred to as trisomy 21

E

egestion the removal of waste food materials from the body

electrocardiograph a device that detects the electrical activity of the heart through electrodes placed on the body's surface

emesis the expulsion of stomach contents through the esophagus and the mouth; also known as vomiting

endodermis the innermost layer of cells in the cortex of a root

endoscopy any medical procedure that uses an endoscope to look inside the body

endosperm the nutritive tissue in an angiosperm seed

endospore a dormant structure that forms inside certain bacteria in response to stress; protects the cell's chromosome from damage

endosymbiosis a relationship in which a single-celled organism lives within the cell(s) of another organism; recent findings suggest this may be very common

enterokinase an enzyme of the small intestine that converts inactive trypsinogen into trypsin

enzyme any chemical produced by cells that facilitates biochemical reactions in the body, such as those involved in digestion and metabolism; all enzymes are proteins

epidemic a large-scale outbreak of disease; usually confined to a limited geographic region

erythrocyte a red blood cell

esophagus an organ consisting of a muscular tube that passes food from the pharynx to the stomach

eukaryote any organism whose cells contain organelles; some eukaryotic organisms are single-celled, while others are multicellular

evolution the scientific theory that describes changes in species over time and their shared ancestry

evolutionary change a change that occurs in an entire population; usually occurs over a long period of time

expiratory reserve volume the volume of air that can be forcibly exhaled after a normal exhalation

external intercostal muscle a muscle that raises the rib cage, decreasing pressure inside the chest cavity

F

F_1 generation the offspring of a P generation cross

F_2 generation offspring of an F_1-generation cross

facilitated diffusion the diffusion of molecules across a cell membrane via a transport protein

facultative aerobe an organism that can live with or without oxygen

feces the undigested material that is eliminated as waste from the body

fermentation an anaerobic process that releases chemical energy from food

fertilization the formation of a zygote by the joining together, or fusion, of two gametes

fibrous root system a root system made up of many small, branching roots

filament the thin stalk that supports the anther

FLAP inhibitors a category of drugs that interfere with the production of chemicals that cause inflammation

flower the specialized reproductive structure of an angiosperm; produces pollen and/or ovules

fossil any ancient remains, impressions, or traces of an organism or traces of its activity that have been preserved in rocks or other mineral deposits in Earth's crust

founder effect genetic drift that results when a small number of individuals separate from their original population and establish a new population

fragmentation a method of asexual reproduction in which a piece or body fragment of the parent organism develops into a mature individual

frond a fern leaf; young curled fronds are often called "fiddleheads" because of their distinctive shape; some fiddleheads are edible, but many are toxic

fruit the mature ovary (or ovaries) of flowering plants that contain seeds; fruit help protect and disperse seeds

functional genomics the study of the relationship between genes and their function

G

gamete a sex cell; includes sperm cells in males and egg cells in females

gametogenesis the production of gametes (sex cells) in animals

gametophyte a haploid organism that produces haploid sex cells in an alternation of generations life cycle

gas exchange the processes whereby the body cells obtain oxygen and get rid of carbon dioxide

gastrin a hormone that stimulates the release of hydrochloric acid and pepsinogen in the stomach

gastrointestinal tract (GI tract) the passageway or tube that extends from the mouth to the anus and in which the process of digestion takes place

gastrovascular cavity a simple, sac-like digestive cavity that has only one opening through which food is taken in and wastes are expelled

gemma a small clump of haploid photosynthetic cells produced in little cup-shaped structures on the gametophyte plant; dispersed by splashes of rain to grow into another gametophyte plant

gene a segment of a DNA molecule that codes for a particular trait; found at a specific location on a chromosome

gene pool the complete set of all alleles contained within a species or population

gene therapy a method of treating disease in which genes are introduced into cells to replace, supplement, or repair a defective gene

genetic bottleneck a dramatic, often temporary, reduction in population size, usually resulting in significant genetic drift

genetic diversity the genetic variability among organisms; usually referring to individuals of the same species

genetic drift changes to allele frequency as a result of chance; such changes are much more pronounced in small populations

genetic screening tests used to identify the presence of a defective allele that leads to a genetic disorder

genetically modified organism an organism in which the genetic material has been altered using genetic engineering techniques

genetics the branch of biology dealing with heredity and the variation of inherited characteristics

genotype the genetic makeup of an individual

genus a taxonomic level containing a group of similar species

germ layer one of three layers that form during early embryonic development in most animals

grafting attaching a young branch from one plant to the stem and root of another plant

gravitropism a directional change in growth pattern in response to gravity

growth the process of cell enlargement

guard cell one of two kidney shaped cells that control the opening and closing of a stoma

gymnosperm a vascular plant that produces seeds in special structures called cones; gymnosperms are a major plant group

H

half-life the time required for half the quantity of a radioactive substance to undergo decay; the half-life is a constant for any given isotope

haploid a cell containing half the usual complement of chromosomes (n)

Hardy–Weinberg principle in large populations in which only random chance is at work, allele frequencies are expected to remain constant from generation to generation

harmful mutation any mutation that reduces the reproductive success of an individual and is therefore selected against; harmful mutations do not accumulate over time

hemoglobin the protein in red blood cells that bonds with oxygen and enables the transport of oxygen around the body

hemolymph a mixture of blood and tissue fluid that is the circulating fluid in an open circulatory system

herbaceous describes plants with stems that do not have wood

heredity the passing of traits from parents to offspring

heterotroph an organism that obtains energy-rich nutrients by consuming living or dead organisms

heterozygous describes an individual that carries two different alleles for a given characteristic

hominid all species descended from the most recent common ancestor of chimpanzees and humans that are on the human side of the lineage

homologous chromosomes matching pairs of chromosomes, similar in size and carrying information for the same genes

homologous feature a structure with a common evolutionary origin that may serve different functions in modern species (for example, bat wing and human arm)

homozygous describes an individual that carries two of the same alleles for a given characteristic

horizontal gene transfer the transfer of genetic information from one species into a different species

horizontal gene transfer any process in which one species gets DNA from a different species; also called "lateral gene transfer"

hormone a chemical signal or messenger molecule, circulated through the body and used to coordinate cellular functions

human genome the sequence of DNA nitrogenous bases found on the 23 sets of chromosomes in humans

Human Genome Project (HGP) a collaborative worldwide project to sequence the nitrogenous bases in human DNA

hybrid the offspring of two different true-breeding plants

hybridization the cross-breeding of two different species

hypertension consistent blood pressure above the range of normal values; also called high blood pressure

hypha a thin filament that makes up the body of a fungus

I

immutable unable to change

incomplete dominance a situation where neither allele dominates the other and both have an influence on the individual; results in partial expression of both traits

induced mutation a mutation that occurs because of exposure to an outside factor; second hand smoke increases the chance of developing lung cancer

inorganic chemical a chemical that has an abiotic origin; some simple substances that are produced by organisms are also classified as inorganic

inspiratory reserve volume the volume of air that can be forcibly inhaled after a normal inhalation

internal intercostal muscle a muscle that pulls the rib cage downward, increasing pressure inside the chest cavity

interphase the portion of the cell cycle between mitotic divisions when the genetic material (in the form of chromatin) is duplicated

invertebrate an animal that does not have a backbone; the great majority of animal species are invertebrates

K

karyotype the chromosomes of an individual that have been sorted and arranged according to size and type

kingdom the highest taxonomic level of the traditional Linnaean system of classification

L

lacteal a lymphatic vessel within a villus, through which digested fats enter the circulatory system

lateral meristem (cambium) plant tissue consisting of actively dividing cells that produce secondary growth

lateral root a smaller root that branches from a larger root

law of independent assortment if genes are located on separate chromosomes, they will be inherited independently of one another

law of segregation a scientific law stating that (1) organisms inherit two copies of genes, one from each parent, and (2) organisms donate only one copy of each gene to their gametes because the genes separate during gamete formation

leukocyte a white blood cell

lignin an important structural compound found in the vascular tissues of plants; it is responsible for the strength of wood

lipase an enzyme that digests lipids

locus the location of a gene on a chromosome

lung transplant the surgical procedure of replacing a diseased lung with part or all of a whole healthy lung from a donor

lycophyte a seedless vascular plant; club mosses are examples of lycophytes

lymph tissue fluid collected in lymph vessels and returned to the blood

lymph node an enlargement in the lymph vessels that acts as a filter to remove bacteria and foreign particles

lysis the rupturing of a cell; can occur when newly made viruses are released from a host cell

lysogeny a state of dormancy in which viral DNA may remain within a host cell's chromosome for many cell cycle generations

M

macroevolution large-scale evolutionary changes including the formation of new species and new taxa

macronutrients plant nutrients needed in large quantities

magnetic resonance imaging (MRI) scan an imaging technology that produces images by using a magnetic field to change the orientation of hydrogen atoms in tissues

maternal inheritance a type of inheritance in which a zygote formed from two gametes inherits cytoplasmic DNA from only the female gamete

meiosis a form of cell division in which a single cell gives rise to four haploid daughter cells

meristematic tissue (meristem) tissue consisting of dividing undifferentiated cells (meristematic cells) found in areas of the plant where growth can take place

mesophyll the photosynthetic middle layer of cells in the leaf of a terrestrial plant

metabolic rate the rate at which the body converts stored energy into working energy

metabolism the set of chemical reactions that occur in living organisms that are necessary to maintain life

microarray a small membrane or glass slide that has been coated in a predictable and organized manner with a genomic sequence

microevolution changes in gene (allele) frequencies and phenotypic traits within a population and species

micronutrients plant nutrients needed in small quantities

microvillus a microscopic projection of the cell membrane of certain types of epithelial cells; greatly increases the surface area of the cell

mineral an element, such as calcium or phosophorus, required by the body in small amounts; plays a role in cell processes and repair

mitosis the process by which a eukaryotic cell divides the genetic material in its nucleus into two new identical nuclei

model organism an organism that can be used to study biological functions of another organism, due to its genetic similarity

modern evolutionary synthesis the modern theory of evolution that takes into account all branches of biology

monohybrid the offspring of two different true-breeding plants that differ in only one characteristic

monohybrid cross a cross designed to study the inheritance of only one trait

monosomy a chromosomal abnormality in which there is a single chromosome in place of a homologous pair

morphology the physical appearance and characteristics of an organism; also the science of the study of these physical characteristics

mucus a protective secretion produced by the epithelial cells that form the mucous membrane

mutation a change in the genetic code of an allele; the change may have a positive effect, a negative effect, or no effect

mutualism a relationship between two species that live in very close association with each other, whereby each benefits from the association

mycelium a branched mass of hyphae

mycorrhiza a symbiotic relationship between a fungus and a plant root

myocardial infarction the death of cardiac muscle tissue due to oxygen deprivation; also known as a heart attack

myogenic muscle muscle that can contract and relax without input from an external source

N

natural selection the way in which nature favours the reproductive success of some individuals within a population over others

nausea the feelings associated with having the urge to vomit

nematocyst a capsule within specialized cells of cnidarians containing toxins that can be propelled toward attackers and prey, causing them to be paralyzed; also called a stinging cell

neutral mutation a mutation that does not result in any selective advantage or disadvantage

non-coding DNA a region of DNA that does not contain a sequence of nucleotides that will be expressed

non-disjunction the failure of homologous chromosomes to move to opposite poles of the cell during meiosis; results in an abnormal number of chromosomes in the daughter cells

notochord a flexible rod found in some chordates; in most modern chordates it is replaced by vertebrae during embryonic development

nuclein the original name given to DNA when it was discovered in the nucleus of cells by Friedrich Miescher in 1869

nucleotide the repeating unit in DNA; it comprises a deoxyribose sugar, a phosphate group, and one of the four nitrogenous bases

nutrient a chemical that must be obtained by an organism from its environment in order to survive; nutrients provide the raw material for growth and repair and may be a source of energy

O

obligate aerobe an organism that cannot survive without oxygen

obligate anaerobe an organism that cannot survive in the presence of oxygen

oogenesis the production of mature egg cells

organic chemical in biology, any chemical that contains carbon and is produced by living things; carbon dioxide is an exception—it is produced during respiration but is classified as inorganic

ova female sex cells (egg cells)

ovule a small structure that contains a microscopic haploid female gametophyte

P

P generation the parent plants used in a cross

paleontology the scientific investigation of prehistoric life through the study of fossils

palisade mesophyll the layer of elongated photosynthetic cells arranged in columns under the upper surface of a leaf on a terrestrial plant; part of the mesophyll

pandemic an epidemic that occurs over a widespread geographic area, often globally

partial pressure the pressure of each of the individual gases that make up the total pressure of a mixture of gases

passive transport the movement of materials across a cell membrane without any expenditure of the cell's energy

paternal inheritance a type of inheritance in which a zygote formed from two gametes inherits cytoplasmic DNA from only the male gamete

pathogen a disease-causing agent, often a virus or micro-organism

pedigree a diagram of an individual's ancestors used in human genetics to analyze the Mendelian inheritance of a certain trait; also used for selective breeding of plants and animals

pepsin a protein-digesting enzyme produced in the stomach

perforation plate the perforated end wall of a vessel element

pericardium a two layered fluid filled membrane that surrounds the heart and prevents friction between the heart and other tissues and organs

pericarp the fruit wall, which develops from the ovary wall of a fertilized angiosperm carpel

peristalsis the rhythmic, involuntary wave-like contractions of the smooth muscles of the gastrointestinal tract

petiole the stalk that attaches the leaf blade to the plant stem

phenotype an individual's outward appearance with respect to a specific characteristic

phenylketonuria (PKU) an autosomal, recessive, inherited genetic disorder that results in the accumulation of phenylalanine in the tissues and blood

phosphorylation the addition of a phosphate group to a molecule; in aerobic cellular respiration the phosphate group is added to ADP, creating the ATP molecule in which energy is stored

photoperiodism a plant's response to changing day length

photopigment a pigment that undergoes a physical or chemical change in the presence of light

photoreceptor a molecule that detects light; different photoreceptors detect different wavelengths of light

phototropism a change in direction of a growing plant in response to light

phylogenetic tree a diagram depicting the evolutionary relationships between different species or groups

phylogeny the study of the evolutionary relatedness between, and among, species

pioneer species the first species to colonize an area during succession

plant growth regulator a chemical produced by plant cells that regulates growth and differentiation

plaque deposits of fat, cholesterol, calcium, and other materials on and in the walls of arteries

plasma the liquid component of blood in which blood cells are suspended

plasmid a small loop of DNA often found in prokaryotic cells; usually contains a small number of genes

plate tectonics the scientific theory that describes the large-scale movements and features of Earth's crust

platelet a cell fragment in the blood that is necessary for blood clotting

pleural membrane a thin layer of connective tissue that covers the outer surface of the lungs and lines the thoracic cavity

pneumonia an infection of the lungs that causes the alveoli to fill with pus and mucus, preventing gas exchange

pneumothorax a collapsed lung caused by the introduction of air between the pleural membranes

point mutation a small-scale change in the nitrogenous base sequence of a DNA; the mutation may be beneficial, harmful, or neutral (having no effect on the organism)

pollen small structures called "grains" that contain a microscopic haploid male gametophyte

pollen tube a hollow tube that grows out of a pollen grain and carries the pollen nucleus to the female sex cell

pollination the transfer of pollen grains to an ovule

polyploid having more than two sets of chromosomes; many plants are polyploids

positron emission tomography (PET) scan an imaging technology that produces cross-sectional images from gamma rays emitted by a radioactive tracer injected into body tissues

postzygotic mechanism a reproductive isolating mechanism that prevents maturation and reproduction in offspring from interspecies reproduction

prenatal testing testing for a genetic order that occurs prior to birth

prezygotic mechanism a reproductive isolating mechanism that prevents interspecies mating and fertilization (for example, ecological isolation, temporal isolation, and behavioural isolation)

primary growth plant growth originating from the apical meristems throughout the life of the plant; results in increases in length and any growth in the diameter of stems and roots that occurs in the first year

primary succession succession in an area that has no plants, animals, or soil

primate a group of relatively large-brained, mostly arboreal mammals that include prosimians, monkeys, apes, and humans

prion an abnormally shaped infectious protein responsible for some brain diseases of mammals, including humans

probability the likelihood that an outcome will occur if it is a matter of chance

product law the probability of two independent random events both occurring is the product of the individual probabilities of the events

prokaryote a single-celled organism that does not contain membrane-bound organelles

prosimian the group of primates that includes lemurs, lorises, and tarsiers

protostome an animal with bilateral symmetry; during embryonic development, the mouth forms before the anus

pseudogene a vestigial gene that no longer codes for a functioning protein

psychotropic mind-altering

pterophyte a seedless vascular plant; ferns are examples of pterophytes

pulmonary circuit the part of the circulatory system that delivers blood to the lungs

Punnett square a diagram that summarizes every possible combination of each allele from each parent; a tool for determining the probability of a single offspring having a particular genotype

Purkinje fibre a conducting fibre that carries the electrical signals from the atrioventricular (AV) node to the muscle cells of the ventricles

pus a yellowish-white fluid formed in infected tissue, consisting of white blood cells and cellular debris

R

radial symmetry symmetry around a central axis

radioisotope an atom with an unstable nucleus that is capable of undergoing radioactive decay

recessive allele the allele that is expressed only if it is not in the presence of the dominant allele, that is, if the individual is homozygous for the recessive allele

recombinant DNA a fragment of DNA consisting of nucleotide sequences from at least two different sources

rectum the lower 20 cm of the large intestine, generally referred to as the lower bowel, where feces are stored

reproductive isolating mechanism any behavioural, structural, or biochemical trait that prevents individuals of different species from reproducing successfully together

residual volume the volume of air remaining in the lungs after a forced exhalation

restriction enzyme a molecule that has the ability to cut DNA at a specific site; different restriction enzymes recognize and cut different sites

rhizome a horizontal underground stem

RNA (ribonucleic acid) a nucleic acid found in all cells and some viruses; usually carries genetic information that provides instructions for synthesizing protein

root cap the mass of cells that form a protective covering for the meristem at the root tip

root cortex a region of parenchyma cells under the epidermis of a root

root hair a microscopic extension of the epidermal cells of the root

root pressure the osmotic force pushing xylem sap upward in root vascular tissue

S

scientific model a simplified representation of a concept; can be tangible or conceptual

scion the detached young branch from a plant

secondary growth growth that occurs from lateral meristems and results in an increase in girth

secondary succession succession in an ecosystem that has been disturbed by a natural event or human activity

secretin a hormone secreted by the duodenum that stimulates pancreatic and bile secretions

seed a plant structure containing an embryo and a food supply, surrounded by a protective outer covering called the seed coat

self-pollination the transfer of pollen from one flower to another on the same plant

semilunar valve the valve located between the left ventricle and the aorta and the right ventricle and the pulmonary arteries to prevent the backflow of blood when the ventricles relax

senescence developmental events in a plant tissue or organ from maturity to death

septum a wall of tissue that divides a body cavity or structure into smaller parts; for example, the ventricle of a mammal's heart is divided into two cavities by a septum

serum the fluid that results when the cells, platelets, and fibrinogen have been removed from whole blood

sex chromosomes chromosomes that differ in males and females of the same species; the combination of sex chromosomes determines the sex of the offspring

sex-linked describes an allele that is found on one of the sex chromosomes, X or Y, and when passed on to offspring is expressed

sexual reproduction the production of offspring from the fusion of two sex cells (usually from two different parents); the genetic makeup of the offspring is different from that of either parent

sexual selection differential reproductive success caused by variation in the ability to obtain mates; results in sexual dimorphism, and mating and courtship behaviours

sieve cell a phloem cell with pores in its cell walls; contains all necessary cell organelles

sieve plate the perforated end wall of a sieve tube element

sieve tube element a phloem cell with pores in its side cell walls and a sieve plate at the end walls; sieve tube elements lack organelles and depend on associated companion cells

sink a plant cell with a low concentration of sugars; sugars may be converted to starch for storage or used rapidly for energy or as building blocks of other carbohydrates

sinoatrial (SA) node a mass of muscle and nerve cells in the right atrium; initiates the heartbeat and maintains the regular rhythm

sister chromatid the identical copy of a single chromosome that remains attached to the original chromosome at the centromere

source a plant cell with a high concentration of sugars and other solutes, such as a leaf cell

speciation the formation of new species

species all organisms capable of breeding freely with each other under natural conditions

species diversity a measure of diversity that takes into account the quantity of each species present, as well as the variety of different species present

spermatogenesis the production of mature sperm cells

sphincter a circular muscle that contracts to close an opening in the body

spirillum a spiral or corkscrew-shaped bacterial cell

spleen the largest organ of the lymphatic system; acts as a filter and a reservoir of erythrocytes and leukocytes

spongy mesophyll the layer of loosely packed photosynthetic cells with large air spaces between them under the lower surface of a leaf on a terrestrial plant; part of the mesophyll

spontaneous mutation a mutation that is not caused by any outside factors; it occurs randomly

sporangium the structure in which spores are produced

spore a haploid reproductive structure; usually a single cell; capable of growing into a new individual

sporophyte a diploid organism that produces haploid spores in an alternation of generations life cycle

stabilizing selection selection against individuals exhibiting traits that deviate from the current population average

stamen the male reproductive floral part, comprising an anther and a filament

stigma the sticky surface on top of the style

stock the plant onto which a scion is grafted

stoma a small opening in the epidermis of a plant that allows gas exchange; also called stomate

structural diversity the range of physical shapes and sizes within a habitat or ecosystem

style the stalk that leads to the ovary

succession the gradual change over time in the species that form a community

survival of the fittest a phrase that has been used to describe the process of natural selection

sympatric speciation the evolution of populations within the same geographic area into separate species

synapomorphy a derived trait shared by two or more species or groups

synapsis the physical pairing up of homologous chromosomes during prophase I of meiosis

systemic circuit the part of the circulatory system that delivers blood around the body

systole the period of the cardiac cycle when the ventricles contract; blood is ejected from the ventricles

systolic pressure the blood pressure in the arteries when the heart contracts

T

taproot system a root system composed of a large, thick root; can have smaller lateral roots

target cell one of the cells that contain the faulty gene to be corrected

taxon a category used to classify organisms

taxonomy the science of classifying all organisms; taxonomists classify both living and fossil species

test cross a cross used to determine the genotype of an individual expressing a dominant trait

tetrad a pair of homologous chromosomes, each with two sister chromatids

theory of gradualism a theory that attributes large evolutionary changes in species to the accumulation of many small and ongoing changes and processes

theory of punctuated equilibrium a theory that attributes most evolutionary changes to relatively rapid spurts of change followed by long periods of little or no change

thigmotropism a directional change in growth pattern in response to touch

thymus a glandular organ of the lymphatic system; secretes hormones to promote the maturity of lymphocytes

tidal volume the volume of air inhaled or exhaled during a normal, involuntary breath

total lung capacity the maximum volume of air that can be inhaled during a single breath

trachea the tube leading from the mouth toward the lungs

tracheid an elongated, tapered xylem cell with thick cell walls containing small pits; tracheids overlap one another at the ends to form continuous tubes from root to shoot

trait a particular version of a characteristic that is inherited, such as hair colour or blood type

transduction a type of gene transfer in which a virus transfers DNA from one bacterium to another

transformation a process in which a bacterial cell takes in and uses pieces of DNA from its environment

transitional form a fossil or species intermediate in form between two other species in a direct line of descent

translocation long-distance transport of substances through the phloem, particularly glucose

transpiration evaporation of water through the stomata of plant leaves

transposition the process of moving a gene sequence from one part of the chromosome to another part of the chromosome

transposon a specific segment of DNA that can move along or between the chromosomes

triglyceride a lipid composed of glycerol and three fatty acids that are bonded together

trisomy a chromosomal abnormality in which there are three homologous chromosomes in place of a homologous pair

tropism a directional change in growth or movement in response to a stimulus

true-breeding organism an organism that produces offspring that are genetically identical for one or more traits when self-pollinated or when crossed with another true-breeding organism for the same traits

trypsin a protein-digesting enzyme produced from trypsinogen

tuberculosis (TB) a bacterial infection that damages the tissues of the lungs and interferes with gas exchange

tuberous root a lateral root specialized to store carbohydrates

turgor pressure caused by the fluid contents of the central vacuole, which pushes against the wall of a plant cell

U

ulcer a lesion or open sore on the epithelium of an organ

uniformitarianism the theory that geological changes are slow and gradual and that natural laws and processes have not changed over time

V

vascular bundle the arrangement of vascular tissue that consists of xylem and phloem

vascular cambium the meristematic cell layer in vascular tissue

vascular cylinder the central portion of a root that contains the xylem and the phloem

vasoconstriction a decrease in the diameter of arterioles that decreases the blood flow to tissues

vasodilation an increase in the diameter (dilation) of arterioles that increases the blood flow to tissues

vector any agent, such as a plasmid or a virus, capable of inserting a piece of foreign DNA into a cell

venation the arrangement of veins within a leaf

ventilation the process in more complex organisms that ensures a flow of oxygen-rich air to the lungs

ventricle a chamber of the heart that pumps blood to the body

venule the smallest vein; formed by the merging of capillaries

vertebrate an animal with a backbone or a notochord

vessel element a shorter, blunt-ended xylem cell with thick cell walls containing small pits; vessel elements are stacked end to end to form vessel tubes that run from root to shoot

vestigial feature a rudimentary and non-functioning, or only marginally functioning, structure that is homologous to a fully functioning structure in closely related species

villus a small, finger-like projection of the inner layer of the small intestine mucosa

viroid a very small infectious piece of RNA responsible for some serious diseases in plants

virus a small infectious particle containing genetic material in the form of DNA or RNA within a protein capsule

vital capacity the maximum amount of air that can be inhaled or exhaled

vitamin an organic molecule that the body requires in small amounts as an essential nutrient

VO_2 an estimated or measured value representing the rate at which oxygen is used in the body, measured in millilitres per kilogram per minute

VO_2max the maximum rate at which oxygen can be used in an individual, measured in millilitres per kilogram per minute

W

woody describes plants with stems that contain wood

X

X-linked phenotypic expression of an allele that is found on the X chromosome

X-ray crystallography a technique in which a pure substance is subjected to X-rays; the pattern in which the X-rays bend and spread helps reveal the structure of the pure substance

Y

Y-linked phenotypic expression of an allele that is found on the Y chromosome

Z

zygote a cell formed by the fusion of two sex cells; the zygote is diploid ($2n$)

Index

100-year experiment, 286

A

Abiogenesis, 348
Abiotic conditions, 10, 326
A blood type, 195–196
Abnormal meiosis, 161–163
Abscisic acid (ABA), 617
Absorption, 406
Abstract, 660
Access to Genetic Information, 208
Accuracy, 664–665
Achondroplasia, 283
Acid reflux, 410
Acquired characteristics, 288–289
Active processes, 671
Active transport, 417, 565
Adaptation, 288–289, 304
Adaptive radiation, 341–342
Additive allele, 214
Adenine, 229, 230
Adenosine diphosphate (ADP), 438
Adenosine triphosphate (ATP), 438
Adventitious roots, 561
Adventure Tour Guide, 60
Aerenchyma, 549
Aerobic, 61
Aerobic cellular respiration, 438
Aetiocetus, 354
Africa, 312
African cichlids, 342
Agar, 60
Agouti, 344
Agranular leukocytes, 483
Agrobacterium tumefaciens, 246
Air pressure, 447
Algae, single celled, 228
Alkaptonuria, 206
Allele
  additive, 214
  definition of, 187
  influence on phenotypes, 188
  notation of, 194
  prediction of inheritance, 188
Alligators, 30–31
Allopatric speciation, 337
Aloe vera, 549
Alternation of generations, 65
  and animals, 87
Alternatives, 661
Altitude, 447
  and effect on respiration, 449
Alveoli, 441, 448, 452, 453
Alveolus, 441
Amber, 290
Amborellales, 544
Amino acids, 401, 410
Amniotic egg, 103
Amylase, 408
Anabolism, 397
Analogous features, 300
Analyses, 121, 525, 651, 652, 653, 654
Analyze and evaluate, 121, 525, 651, 652, 653
Anaphase, 144
Anaphase I, 154
Anaphase II, 155
Anatomical oddities, 300–301
Anatomy of herbaceous stems, 553
Anatomy of woody stems, 553
Ancestral eukaryotic cell, 61
Ancestral prokaryotic cell, 61
Anchiornis huxleyi, 30
Anemia, 484
Angel fish, 15
Angina, 501
Angiogram, 504
Angioplasty, 502
Angiosperms, 91–94, 93–94, 544, 601
  evolved relationships, and, 544
  life cycle of, 599
  and sexual reproduction, 597–599
Aniline sulfate, 659
Animal breeder, 286
Animal cloning, 147
Animal products, 401
Animals, 27, 96–107
  characteristics of, 98
  classification of, 97–98
  importance of, 97
  phylogenetic tree of, 98
  phylogeny of, 97–98
  and safe handling of, 647
  traits of, 329
Anopheles, 64
Anorexia nervosa, 404
Antarctica, 312
Anther, 598
Antheridia, 89
Antheridium, 89
Anthropoid, 358
Anthropologist, 361
Antibiotic, 47, 51, 454
Antibiotic resistance, 51, 237
Antifreeze gene, 246
Antimicrobial chemicals, 277
Anus, 418
Aorta, 487
Apes, 242
Aphids, 142
Apical dominance, 615
Apical meristem, 605, 606
Application, 121, 378, 525, 651, 654, 661–662
Applications of cloning, 148
Apply and extend, 121, 379, 525, 651, 652, 653, 654
Aquatic ecosystems, 78
Aquatic vascular plants, 549
Arborist, 80
Archaea, 26, 27, 28, 46–53
  domain, 51–52
Archaebacteria, 26
Archaeopteryx, 30, 354
Archegonia, 89
Archegonium, 89
Arctic poppies, 86
Aristotle, 288
"arms race," 277
Arteries, 487–488
Arterioles, 488
  and blood flow, 488–489
Arteriosclerosis, 501–503
Artificial blood, 485–486
Artificial insemination, 164, 165
Artificial lungs, 460
Artificial reefs, 10
Artificial selection, 283, 285–286
Asexuality, 8, 64, 82
Asexual reproduction, 142–151
  costs and benefits, 593
  and cytoplasmic inheritance, 167
  definition of, 139
  and human use of, 593–594
  modes of, 142–143
  in seed plants, 592–594
  and structures, 592
Assessment checklist, 121, 265, 379, 525, 631
Assisted Reproductive Technologies (ARTs), 163
Asthma, 452–453
Atherosclerosis, 501, 506
Athlete's foot, 84
Atomic theory, 280
Atria, 497
Atrioventricular (AV) node, 499
Atrioventricular valves, 496
Atrium, 480
Australia, 344
Australopithecus africanus, 359
Automated external defibrillators (AEDs), 476
Autosomal inheritance, 200
Autosomes, 159, 235

Autotrophs, 10
Auxins, 615
Aves (birds), 31, 105
AV node, 500

B

Bacillus bacteria, 46, 49
Bacillus thuringiensis (Bt) corn, 247–248
Bacteria. *see also* eubacteria
  diseases of, 51
  shapes of, 49
Bacteriophages, 55
"bad cholesterol," 501
Balloon angioplasty, 502
Bar graphs, 666
Bark, 554
Basal metabolic rate (BMR), 398
Basidiomycota (basidiomycetes), 81
  life cycle of, 83
B blood type, 195–196
Beans, 610
Beaver fever, 60
Benedict, Francis G., 398
Beneficial mutation, 282, 310
Benyus, Janine, 571
Bicarbonate ions, 415
Bilateral symmetry, 97
Bile, 415, 416
Binary fission, 49, 64
Binge-purge behaviour, 404–405
Binomial nomenclature, 16
BioArts International, 150
Biodiesel, 604
Biodiversity, 6–13, 590
  definition of, 8
  and fisheries in peril, 108–109
  and genetic diversity, 9
  hotspot, 95
  introduction to, 8–13
  at risk, 12–13
Bioethicist, 242
Biofilms, 50
Biofuel, 603–604
Biogeography, 296–297
Bioharzardous infectious materials, 644
Biological change, 282–287
Biological classification, 14
Biological drawings, 655
Biological evolution and cultural evolution, 362
Biology Journal, 30–31, 202–203, 294–295, 356–357, 424–425, 571–572
Biomaterials engineer, 247
Biomimicry, 571–572
Biomimicry: Innovation Inspired by Nature (Benyus), 571
Biotechnology, 58, 146
Biotic factors, 326
Bird monogamy, 366–367
Birds as unique class, 30
Birth mass, human, 327
Black Mamo (*Drepanis funerea*), 297
Blade, 547
Blarina brevicauda, 18
Blood
  artificial, 485–486
  cellular components of, 482–483
  definition of, 482
  substitutes, 485–486
  transfusions, 484
Blood cells, 484
Blood clot, 483, 502
Blood count, 484
Blood flow
  and arterioles, 488–489
  in capillaries, 489–490
Blood glucose levels, 508
Blood plasma, 448
Blood pressure, 491–492
  mini investigation, 477
Blood substitutes, 485–486
Blood types, 195–196, 484–485
  and codominance, 195–196
  and dominance, 195–196
Blood vessels, 479, 487–494
Blue blood, 448
Blue-green algae, 48, 50, 83, 99
Body cells, 439
Body mass index (BMI), 404
Boreal forests, 93
Botanist, 16, 87
Bottlenecks, genetic, 332
Botulism, 51
Bovine spongiform encephalopathy (BSE), 58
Boyer, Herbert, 245
Brachial artery, 504
"brain dead," 498
Brassica oleracea, 284
Brazil nut trees, 344
Bread mould fungus, 152
Breast cancer, 205
Breathing, 450–451
Breeder, animal, 286
Breeder, plant, 286
Breeding, science of, 285
Breeding potential, 302
Broad Street, 424
Bromeliads, 331
Bronchi, 441
Bronchial thermoplasty, 459
Bronchioles, 441, 452
Bronchus, 441
Brown algae, 65
Bryophytes, 89–90
BSE (bovine spongiform encephalopathy), 58
Bt (*Bacillus thuringiensis*) corn, 247–248
"bubble baby," 249
"buds," 142
Bulb, 479
Bulimia, 404–405
Bypass surgery, 502–503
By product, 448

C

Cacao (*Theobroma cacao*) beans, 47
Cacti, 343
Calcium, 403, 609
Calories, 398
Cambrian explosion, 350
Cambridge University, 230
Camellia sinensis, 546
Canadian Boreal Forest Conservation Framework, 93
Canadian Breast Cancer Foundation, 209
Canadian College of Medical Geneticists, 204
Canadian Hazardous Products Act, 643
Canadian Journal of Diabetes, 660
Canadian Metric Practice Guide, 669
Canadian Museum of Nature (Ottawa), 311
Canadian Standards Association, 669
Cancer, 54, 84, 205, 236, 457–458
Canis lupus familiaris, 283
Capillaries, 413
  and blood flow, 489–490
Capillary action, 566
Capillary network, and absorption of nutrients, 417
Capsid, 54
Capsule, 49
Capsule endoscope, 420
Carbaminohemoglobin, 449
Carbohydrates, 400–401
  definition of, 542
Carbon Copy the Cat, 150
Carbon dioxide, 438, 447
  diffusion, 448–449
  maintenance levels of, 450–451
  transport, 448–449
Carbonic acid, 449
Cardiac arrest, 502
Cardiac calcium score, 506
Cardiac catheterization, 504
Cardiac cycle, 495–500, 497–500
Cardiopulmonary resuscitation (CPR), 476, 648
Career links, 668
Career pathways, 668
Carmanah Walbran Provincial Park, 93
Carnivora of mammals, 22
Carnivores, 14
Carpel, 598
Carrier testing, 204
Casparian strip, 559, 565, 566
Catabolism, 397

Catastrophism, 291–292
Catheter, 504
Cecum, 418
Celera Genomics, 240
Cell, 448
  division, 138, 143–145
  specialization, 98
  theory, 280
Cell types in vascular tissues, 554–555
Cellular components of blood, 482–483
Cellulose, 400
Charophyte, 86
Chase, Martha, 228
Cheese maker, 47
Chemical composition of DNA, 229
Chemical defenses, 277
Chemical digestion
  in the mouth, 408
  in the small intestine, 414–416
  in the stomach, 410
Chemical energy, 396, 542
Chemical reactions, 397
  and fruit juice, 415
Chemical safety, 647
Chengdu research facility (China), 165
Chimpanzee and human chromosomes, 368–369
Chitin, 82
Chlorophyll, 48, 86
Chloroplasts, 61
  definition of, 547
Choanocytes, 99
Cholecystokinin (CCK), 414
Cholera, 424–425
Cholesterol, 501
Chordae tendineae, 496
Chordates, 103
Chromatin, 143
Chromosome mutations, 234–235
Chromosomes, 138
  composition of, 143
  definition of, 139
  homologous, 153
  numbers of, 596
Chronic obstructive pulmonary disease (COPD), 453
Chyme, 409, 414, 415
Circle graphs, 666
Circulation, 496
Circulatory systems, 476–507
  functions of, 478
  need for, 478–481
  two circuit, 481
  types of, 479–481
Citations, 660
Clades, 21
Cladistics, 350–351
Cladograms, 350–352
Class, 17
Class A, compressed gas, 644
Class B, flammable and combustible materials, 644
Class C, oxidizing materials, 644
Class D, biohazardous infectious materials, 644
Class D, toxic materials immediate and severe, 644
Class D, toxic materials long term concealed, 644
Class E, corrosive materials, 644
Class F, dangerously reactive materials, 644
Classification
  of animals, 97–98
  of fungi, 80–81
  nature of, 14–20
  phylogenetic, 24
  of plants, 86–87
  system, 15–17
  traditional, 24
  traditional taxonomic ranks of, 17
"cleaning stations," 11
Climate change, 64, 95, 611
  and plant communities, 88
Cloning
  applications, 148–150
  defined, 146–150
  definition of, 146
  endangered species, 149–150
  genetically modified organisms (GMOs), and, 148
  implications of, 148–150
  pets, 150
Closed circulatory systems, 480
Clostridium botulinum, 51
Cocci, 49
Coccus, 49
Code of Life, and DNA, 228–231
Coding DNA, 240
Codominance, 194–195
  and blood types, 195–196
Coelom, 98
Coevolution, 344
Coffee, 537
Cohen, Stanley, 245
College programs, 668
Colon, 418
Colonial protists, 97
Colorado potato beetle, 282
Combined immunodeficiency (SCID) syndrome, 249
Commercial insulin, 148
"common names," 16
Communication, 379, 650, 660, 662
Community gardens, 601
Companion cells, 555
Comparison of monocot and eudicot roots, 559
Comparison of monocot and eudicot stems, 553
Competition within populations, 301–302
Competitors, 102
Complementary base pairing, 231
Complete dominance, 194
Compound microscope, 656–657
Compressed gas, 644
Computerized tomography (CT) scan, 505
Concentration gradient, 416
Cones, 152
Conifers, 92–93, 549, 586
Conjugation, 50, 64
Conservation Biologists, 12
Conservation in action, 121
Continuous variation, 213–214
Controlled experiments, 650–651
Control of breathing, 450–451
Convergent evolution, 343–344
Coral reefs, 11, 64, 102
Corals, 64, 170, 346
Cordyceps, 81
Cork cambium, 554
Cormorants, 338
Corn, 286, 610
Cornell University, 572
Corona, 495
Coronary artery bypass grafting, 503
Coronary artery disease (CAD), 501–503
Coronary blood vessel, 496
Coronary bypass, 503
Correlational studies, 651–652
Corrosive materials, 644
Corrosive solutions, 648
Corrosive symbol, 643
Cortex, 565
Cosmetic chemist, 550
Costs and benefits
  of asexual reproduction, 593–594
  of sexual reproduction, 596
Cotyledons, 93, 544
CPR (cardiopulmonary resuscitation), 476, 648
Creutzfeldt-Jakob disease (CJD), 58
Crick, Francis, 230
Crocodilians, 30–31
Crop plants, 148
Cross, 185
Crossing over, 154
Crossing over errors, 309
Cross-pollination, 599
CT (computerized tomography) scan, 505
Cultural and biological evolution, 362
Cultural evolution, 361–362
Cumulative selection, 330
Cuticle, 89
Cuvier, Georges, 291

Cyanobacteria (blue-green algae), 48, 50, 83, 99
Cycads, 92
Cycle of moss, 90
Cyclosporine, 80, 462
Cystic fibrosis (CF), 204, 206, 235, 242, 282, 455–456
Cytokinesis, 145, 155
Cytokinins, 616
Cytoplasm, 48, 565
Cytoplasmic DNA, 167
Cytoplasmic inheritance, 167–169
  and asexual reproduction, 167
  and genetic variation, 168–169
  and sexual reproduction, 167–168
Cytosine, 229, 231

D

Dangerously reactive materials, 644
Darwin, Charles, 21, 288, 293, 613, 614
  and Darwin's hypotheses, 296–297
  and finches, 341
Darwin, Erasmus, 288
Data, 665
Deafness, 251
Deciduous trees, 586
Decisions, 661–662
Decomposers, 47
Decomposition and fungi, 84
Deoxygenated blood, 490, 496
Deoxyribonucleic acid. *see* DNA
Deoxyribose sugar, 229
Depth of field, 657
Derived traits, 350
Dermal tissues, 543
Deuterostomes, 98, 103–106
  phylogenetic tree of, 104
"dew claw," 300
Diabetes, 508–509
Diagnosis of non-disjunction, 163
Diaphragm, 442, 450
Diarrhea, 422–423
Diastole, 497
Diastolic pressure, 492
Diatoms, 9, 63
Dichotomous keys, 18–19
Dicots, 544
Dietitian, 403
Diets, 394
Differentiation, 605
Differentiation dead-end, 147
Diffusion
  of carbon dioxide, 448–449
  of oxygen, 448
  simple, 416, 417
Digestion, 11
  an introduction, 406–407
  in the large intestine, 417–419
  in the mouth, 408–409
  in the mouth, chemical, 408
  in the mouth, physical, 408
  role of the pancreas in, 414–416
  in the small intestine, 412–417
  of starch, 414
  in the stomach, 409–411
Digestive enzymes, 410
Digestive system, 395, 406
  human, structure of, 407
Digitalis, 550
Dihybrid crosses, 213
  and the law of independent assortment, 210
Dikaryotic, 83
Diplo, 49
Diplococci, 49
Diploid, 64, 82, 88
Diploid cells, 139
Diploid number, 153
Directional selection, 326
Direction of sugar transport, 568
Disaccharides, 400
Discontinuous variation, 213–214
Disease and fungi, 84
Disorders of the respiratory system, 452–456
Disruptive selection, 328
Dissection, 655
Divergent evolution, 342
Diversification, 349–350
Diversity
  in ecosystems, 10
  of habitats, 10
  of interactions, 10
  at risk, 120–121
DNA (deoxyribonucleic acid), 16, 48, 50, 51, 55, 310, 361
  bank, 242
  barcoding, 24–25
  chemical composition of, 229
  and the Code of Life, 228–231
  coding, 240
  defined, 226–234
  definition of, 138
  and egg swapping, 169–170
  and ethics, 208
  extraction, 227
  fingerprinting, 243, 254–255
  and Huntington's disease (HD), 202
  identification of, 242
  "junk," 240
  and legal access to, 208
  a model for, 230–231
  non-coding, 240
  origami, 232–233
  structure of, 230–231
  technology, 24
DNA twist, 231
Dodo, 346
Dog heartworms, 100
Dogs, 309
Dolly (sheep), 147
Dolphins, 311, 343
Domain archaea, 51–52
Domain eubacteria, 47–51
Domain eukaryotes
  and phylogenetic tree, 62
Domains, 28
Domains of life, 28–29
Domestication, 283
Dominance, 187
  and blood types, 195–196
  incomplete, 194
Dominant allele, 187
Dominant factor, 186
Doppler ultrasound, 507
Dormant plant, 568
Double-helix, 230
Down syndrome, 162, 235
Drawing tips, 655
Duchenne muscular dystrophy (DMD), 251
Duodenum, 413, 414
Dust mite allergy, 436

E

Early biological classification systems, 16–17
Earth's age, 308
Earthworm, 152, 406, 480
Eating Well with Canada's Food Guide, 403
Echinoderms, 103
E. coli, 50, 419, 422
Ecologists, 10
Ecosystems, 3
  diversity in, 10
Ectoderm, 98
Ectothermic, 397
Edwards syndrome, 162
Egestion, 406, 419
Egg swapping and DNA, 169–170
EKG, 499
Electrical safety, 647
Electrocardiograph (ECG), 499. *see also* EKG
Elements, 672–673
Ellesmere Island, 357
Elysia chlorotica, 169
Emerald Hole, 52
Emesis, 421
Emphysema, 452, 453
Endangered species and cloning, 149
Endoderm, 98
Endodermis, 559, 565
Endoscopy, 419–420
Endosperms, 596
Endospore, 50

Endosymbiosis, 61
Endothelium, 487
Endothermic, 396, 397
Energy, measurement of, 398–399
Energy requirements, 398–399
Engineering technologist, 556
Enterokinase, 415
Environmental factors and plant growth, 608–612
Enzymes, 408
Eocene mammal, 312
Epidemic, 54
Epidermal cells, 548
Epithelial cells, 487
Equipment and materials, 264, 651, 652, 653, 654
Equisetum, 90
Erosion control, 562–563
Erythrocytes, 482, 484, 485
Erythropoietin (EPO), 449
Escherichia coli. *see* E. coli
Esophagus, 408–409
Essay on the Principle of Population (Malthus), 301
Ethylene, 616
Eubacteria, 26–28, 46–53. *see also* bacteria
  characteristics of, 48–49
  classification of, 47–48
  domain of, 47–51
  key features of, 48
  phylogeny of, 47–48
  reproduction of, 49–50
Eudicot root, 559
Eudicots, 94, 544, 553, 598
Eudicot seeds, 596
Euglena, 63
Eukaryotes, 28, 96, 152
  definition of, 26
  origins of, 61–62
Eukaryotic Protista, 26
Euphorbia, 343
Euphorbia cerifera, 550
European honeybee, 600
Euryarchaeota subgroup, 52
Evaluation, 121, 525, 651, 652, 653, 654, 662
Evidence, 281
Evolution
  of an idea, 288–293
  assessment of evidence, 302
  convergent, 343–344
  definition of, 21
  divergent, 342
  for everyone, 378–379
  human, 358–364
  and human influence, 334–335
  of insect pollination, 330
  of new species, 324
  patterns of, 341–345
  SINEs of, 353
  theory of, 304–307
Evolutionary changes, 16
  definition of, 9
  without selection, 331–332
Evolutionary timeline, 348
Evolution of species
  and human influence, 334–335
Exhalation, 442
Experimental design, 651, 654
Expiratory reserve volume, 443
Explore an issue in biodiversity, 108–109
Explore an issue in biofuels, 603–604
Explore an issue in evolution, 346–347
Explore an issue in healthcare, 463–464
Explore applications in urban greening, 573–574
Explore applications of technology in diabetes management, 508–509
Explosive symbol, 643
Extension, 121, 525, 651, 654
External intercostal muscles, 442, 450
Extinction, 86, 347
  avoidance of, 346–347
Extirpation, 86
Extreme thermophiles, 52
Eye, ear, and face safety, 645

F

F_1 generation, 185
F_2 generation, 185
Facilitated diffusion, 416–417
Facultative aerobe, 49
Family, 17
Family tree, 21, 197
Fats, 402
Feather-duster worms, 100
Feces, 419
Female mate choice, 328
Femoral artery, 504
Fermentation, 49
Ferns, 90–91
Fertilization, 597, 599–600
  definition of, 152
  methods, 152
  problems with, 163–164
Fetal pig dissection, 407, 440, 481, 510–513
Fibrous root system, 558
Field of view, 657–658
Field studies, 653
Filament, 598
Fire classes, 646
Fire safety, 646
First aid, 648
First Law of Mendelian Inheritance, 186–187
Fish, 480
  and respiratory structures, 445
"fishapod," 357
Fisheries in peril, 108–109
Fish gills, 445
Fitness profile, 524–525
Flagella, 99
Flammable and combustible materials, 644
Flammable substances, 648
Flammable symbol, 643
FLAP inhibitors, 459
Fleming, Alexander, 237
Flowers, 93–94, 152, 184
Flu, 454
Fluid, 479
Fluid exchange in capillaries, 489
Flukes, 102
Fluosol, 486
Food
  for energy, 396
  for growth, 396
  for maintenance, 396
  need for, 396–399
  quantity needed, 400–405
  useable for cells, 394
Food and Agriculture Organization of the United Nations, 601
Forelimbs, 298
Forester, 564
Forest fire management, 595
Forest Products Association of Canada, 93
Fossil formation, 289–290
Fossil fuels, 603
Fossil record, 16
  reading the, 291
Fossils, 289, 312, 361
  evidence of, 24
Founder effect, 332
Four-chambered heart, 480
Fragmentation, 143
Franklin, Rosalind, 230
Freshwater biologist, 590
Fronds, 91
Fruit formation, 600
Fruit juice and chemical reactions, 415
Fruits, 93, 600
  human use of, 601
Function
  of the large intestine, 418–419
  of leaves, 547
  of roots, 558
  of stems, 552
Functional genomics, 241
Fungi, 27, 80–84

G

Galactosemia, 206
Galapagos Islands, 295, 338
Gall bladder, 416, 419
Galvani, Luigi, 499
Galvanometer, 499
Gametes, 88, 152, 235, 309

Gametogenesis, 157
Gametophyte, 65
Gaps in scientific theory, 353–354
Gases
  and diffusion of, 447–451
  and transportation of, 447–451
Gas exchange, 438–439, 547
  in the alveoli, 441
  effects of smoking on, 457–458
  interference with, 452–458
Gastric juices, 410
Gastrin, 410
Gastroenteritis, 425
Gastroesophageal sphincter, 409, 410
Gastrointestinal tract (GI tract), 407
Gastrovascular cavity, 406
Gelsinger, Jesse, 249
Gemma, 90
Gemmae, 90
Gene, 138
Gene duplication, 309
Gene hunters, 202–203
Gene order, 210
Gene pool, 309, 333
Genera, 16
Gene therapy, 58, 249–251
Genetically modified organisms (GMOs), 148–149
Genetic bottlenecks, 332
Genetic counsellor, 163
Genetic disorders, 204–207
  and mechanism of inheritance, 206
  and unit task, 264–265
Genetic diversity, 9
Genetic drift, 331, 332, 333
Genetic engineering
  products of, 247–248
  tools of, 245–247
Genetic evidence, 24
Genetic material, 138–139
Genetic profile, 216–217
Genetics
  applications in, 252–253
  definition of, 138
  future of, 133
  gummy bear, 196
  history of, 133
Genetic screening, 204, 208–209
Genetic technology, 252–253
Genetic variation, 282–283
  and cytoplasmic inheritance, 168–169
Genomes, 240–244
  manipulation of, 245–248
Genotype, 187, 190–191
Genus, 16, 17
Geologists, 292
Geology, 292, 313
Germ layer, 98
Giant pandas, 165
Giardiasis, 60
Gibberellins, 616
Ginkgoes, 92
Glassware and safe handling, 645
Glucagon, 508
Glucose, 400, 542
Glucose level, 508
Glycerol molecules, 402
Glycogen, 400
Golden orb spider, 247
Goodall, Jane, 106
"good cholesterol," 501
Goosebumps, 301
Gradualism, 352–353
Grafting, 594
Grand Canyon, 287
Granular leukocytes, 483
Grape plants, 594
Graphs, 666–667
Gravitropism, 614
Great Chain of Being, 17
Greater Toronto Area (GTA), 573
Greek alphabet, 670
Green (γ), 210
Green algae, 86
"greening of" Sudbury, 591
Green sea slug, 169
Ground tissues, 543
Growth, 605
Growth rings, 554, 607
Guanine, 229, 231
Guard cell, 548
Gullet, 63
GULO gene, 311
Gummy bear genetics, 196, 215
Gymnosperms, 91–93, 549
  life cycle of, 597
  and sexual reproduction, 596

H

H1N1, 454
Habitats, diversity of, 10
Half life, 308
Hammerling, Joachim, 228
Haploid cells, 64, 82, 88, 139, 596
Haploid number, 153
Hardy, Godfrey Harold, 333
Hardy-Weinberg principle, 333
Harmful mutation, 282, 310
Harris, J. Arthur, 398
Hawthorn fly, 339
HDL (high-density lipoprotein), 501
Health Canada, 401, 403, 463
Healthcare, 463–464
Health profile, 524–525
Healthy eating, 403
  and balance, 404
Heart, 479
  evolution of the, 480
  structure of the, 495
Heart attack, 502
Heartbeat, 500
Heartburn, 410
Heart rhythm, 498–499
Heart sounds, 498
Heat safety, 646
Helix, 230
Hematologist, 484
Hematology, 479
Hemocytometer, 484
Hemoglobin, 403, 448
Hemoglobin-based oxygen carriers (HBOCs), 486
Hemolymph, 479
Hemophilia, 197, 200, 206, 238
Henslow, John, 294
Herbaceous, 552
Herbaceous stems, 553
Herbert, Paul, 24
Herbivores, 14
Heredity, 136–141, 288–289
  definition of, 138
  nature of, 138–141
  variations in, 194–196
Hermaphroditic, 152
Hershey, Alfred, 228
Heterotrophic bacteria, 49
Heterotrophic fungi, 82
Heterotrophs, 10
Heterozygous, 187, 190
Heterozygous cross, 189
HHPS (Household Hazardous Product Symbols), 643
High-density lipoprotein (HDL), 501
Himalayan mountains, 329
HIV (human immunodeficiency virus), 55
HMS Beagle, 294–295
Hoatzin, 30
Hodgkin's disease, 550
Holstein cows, 148
Hominid evolution, 359
Hominid fossil record, 359
Hominids, 359
  migration routes of, 361
Homo erectus, 361
Homo habilis, 359
Homologous chromosomes, 153
  and random assortment of, 156
Homologous features, 298–300
Homologous genes, 310
Homo neanderthalensis, 359, 361
Homo sapiens, 358, 361
Homozygous, 187, 190
  and dominant cross, 189
  and recessive cross, 189
Homozygous cross, 212

Homozygous dominant, 194
Homozygous recessive, 194
Hooker, Joseph, 296
Horizontal gene transfer, 50, 170
Hormones, 401
Horsetails, 90
Horticulturist, 146
Hose, 479
Hospital for Sick Children (Toronto), 204, 455, 460
Host tree, 560
Hounsfield, Godfrey, 505
Household Hazardous Product Symbols (HHPS), 643
HPV (human papillomavirus), 57
Human activity, 12
  and succession, 590
Human bacterial diseases, 51
Human biological characteristics, 358
Human birth weights, 327
Human chromosomes, 138, 228
  and chimpanzee chromosomes, 368–369
Human digestive system, 407
Human evolution, 358–364, 363–364
Human genome, 240
Human Genome Project (HGP), 226, 240, 242
Human health and vaccinations, 57
Human immunodeficiency virus (HIV), 55, 351
Human legacy, 364
Human papillomavirus (HPV), 57
Human phylogeny, 358–359
Human-protostome interactions, 102
Human races, 363
Human respiratory system, 440
Human selective pressure, 334
Human use
  of asexual reproduction, 593–594
  of leaves, 550
  of roots, 561
  of seeds and fruit, 601
  of stems, 556
Hummingbirds, 326, 327, 599
Humulin, 148
Huntington, George, 202
Huntington's disease (HD), 202–203, 206, 235, 242, 282
Hybrid, 184
Hybridization, 8
Hybrid research farmer, 213
Hybrid species, 339
Hydra, 142
Hygiene, 11
Hyla versicolor, 339
Hypertension, 492
Hypha, 82
Hyphae, 82
Hypotheses, 280, 650, 653

I

IBOL (The International Barcode of Life Project), 24–25
ILA Membrane Ventilator, 460
Ileum, 413
Image fusion, 506
Imaging, 504–507
Immutable, 288
Implications of cloning, 148–150
Incomplete dominance, 194
Induced mutation, 236
Infections, respiratory, 454–456
Infectious cycles of viruses, 56
Infectious disease specialist, 454
Inferences, 304
Infertility, 164
Influenza virus, 283, 454
Ingestion, 406
Inhalation, 442, 450
Inherited blindness, 250–251
Inherited mutations, 235–236
Initiating and planning, 649
Inorganic chemical, 49
Inspiratory reserve volume, 443
Insulin, 148, 508
Interactions in ecosystems, 64
Internal intercoastal muscles, 442
Internal leaf structure, 548
International Barcode of Life Project (iBOL), 24–25
International development, 603
International System of Units (SI), 669
International Union of the Conservation of Nature (IUCN), 346
International Year of Biodiversity (2010), 8
Interphase, 143
Intracytoplasmic sperm injection (ICSI), 164
Invasive tests, 504–507
Invertebrates, 98–101
  protostome, 100–101
  simple, 99
In Vitro Fertilization (IVF), 163–164
Iodine solution, 659
Ipecacuanha, 561
Iroquois peoples, 610
Islets of Langerhans, 508
Isotopes, 308
Issues, 661–662

J

Jade plant, 549
Jane Goodall Foundation, 106
Japanese tea ceremony, 546
Jejunum, 413
Jellyfish, 406
Joule (J), 398
J-shaped organ, 409
"jumping genes," 237
"junk" DNA, 240

K

Kangaroo, 344
Karyotypes
  definition of, 158
  interpretation of, 162, 172–173
Kava kava, 561
Kelp, 60
Kidneys, 492
Kingdoms and domains, 17, 26–29
Kingdoms of life, 26–28
Klinefelter syndrome, 162
Knightia fossil, 289
Koala, 344
Koch, Robert, 425

L

Labelling, 656
Laboratory skills and techniques, 655–659
Lab reports, 653–654
Lab technician, 617
Lacteals, 413
Lactose intolerance, 236
Lactose tolerance, 236, 362
Laetoli, 360
Lake Maracaibo (Venezuela), 202
Lake Temagami (Ontario), 564
de Lamarck, Chevalier, 288, 293
Lambda phage, 56
Lancelot Encore, 150
Landsteiner, Karl, 484
Large billed ground finches, 305–306
Large intestine, 418–419
Laser-assisted hatching (LAH), 164
Lateral meristem (cambium), 605
Lateral roots, 558
Law of independent assortment, 210
Law of segregation, 186
LDL (low-density lipoprotein), 501
Leaf shape, 548
Leaf specializations, 549
Leakey, Mary, 360
Leaves, 543, 546–551
  use by humans, 550
Leber's congenital amaurosis (LCA), 250
Leclerc de Buffon, Georges-Louis, 288
Lesch-Nyhan syndrome, 206
Leukemia, 249, 550
Leukocytes, 483, 484, 493
Levene, Phoebus, 229
Lichen, 83
Life cycle
  of an angiosperm, 599
  of animals, 87–88, 101
  of a basidiomycete, 83
  of a fern, 91

Life cycle (*continued*)
of fungi, 82–83
of a gymnosperm, 597
of protists, 64–66
Light energy, 396, 608
Lignin, 90
Linnaeus, Carl, 16–17, 288
Linnean Society of London, 304
Lipases, 416
Lipids, 402, 415, 416
Lipoproteins, 501
Listeria monocytogenes, 422
Listeriosis, 422
Liver, 416
Liverworts, 89
Livestock, mass production of, 148
Loci, 138
Locus, 138
Low-density lipoprotein (LDL), 501
Lugol's (iodine) solution, 659
Lung cancer, 457–458
Lung capacity, 443
Lungs, 439–440
Lung transplants, 459–462
Lycophytes, 90–91
Lyell, Charles, 291
Lymph, 493
Lymphatic system, 492–494
Lymph nodes, 493
Lysis, 56
Lysogenic cycle, 56
Lysogeny, 56
Lytic cycle, 56

M

Macroevolution, 348–354
Macronutrients, 609
Madagascar long-spurred orchid, 345
Mad cow disease, 58
Magnetic resonance imaging (MRI) scan, 506
Malaria, 60, 64, 66, 282, 326
Male-versus-male competition, 328
Malnutrition, 404
Malthus, Thomas, 301
Mangrove trees, 563
Markers, 202, 485
Marshall, Barry, 410–411
Marsupials, 344
Mass extinction, 12, 349
Mass production
of crop plants, 148
of livestock, 148
Materials, 264, 651, 652, 653, 654
Material Safety Data Sheet (MSDS), 643, 648
Maternal inheritance, 167
Math skills, 663–667
McClintock, Barbara, 237
Measurement error, 664
Medical imaging technologist, 506
Medicine from roots, 561
Meganucleases, 251
Megatherium, 294
Meiosis, 83, 88, 309, 596
abnormal, 161–163
definition of, 153
model of, 157
observation of, 156, 171–172
stages of, 153–156
Meiosis I, 153–155
Meiosis II, 153–156
Melanin, 188
Mendel, Gregor Johann, 184, 185–186
Mendelian inheritance, 184–186
First Law of, 186–187
Meristem, 543
Meristematic tissue, 543
Mesoderm, 98
Mesophyll, 548
de Mestral, George, 571
Metabolic rate, 397
Metabolism, 397
Metaphase, 144
Metaphase I, 154
Metaphase II, 155
Miasmatic theory, 424
Mice, 241, 329
Microarray, 238
Microarray technology, 238–239
Microevolution, 336
Microfluidics, 572
Microhabitats, 10
Micronutrients, 610
Micropipette, 164
Microscope
care and use of, 656–658
compound, 656–657
Microspores, 596
Microvilli, 413
Microvillus, 413
Miescher, Friedrich, 228
Milgaard, David, 243
Minerals, 403
Miscantnus, 603
Missing links in scientific theory, 353–354
Missyplycity, 150
Mistletoe, 563
Mitochondria, 61
Mitosis, 153, 593, 606
and cell division in animals, 144
definition of, 143
phases of, 144–145
Model organism, 241
Modern birds, 30
Modern evolutionary synthesis, 309–311
Modern genetics, 313
Modern paleontology, 312–313
"modern" species, 325
Modern synthesis, 309–311
Modern theory of evolution, 308–313
Modes of asexual reproduction, 142–143
Modes of sexual reproduction, 152
Modes of speciation, 336–339
Modified plant structures, 592
Molars, 408
Monocot roots, 559
Monocots, 94, 545, 552, 553, 598
comparison to eudicot stem, 553
Monocot seeds, 596
Monogamy, 366
Monohybrid cross, 185
Monohybrids, 185
Monosaccharides, 400
Monosomy, 161
de Monte, Jean-Baptiste Pierre Antoine, 288
Morphology, 8, 15
Mosses, 89–90
Mount St. Helens, 588
Mouth, 408
MRI (magnetic resonance imaging) scan, 506
MSDS (Material Safety Data Sheet), 643, 648
Mucosa, 410
Mucus, 408
Mudskippers, 324
Multi-trait inheritance, 210–214
Muscle to fat ratio, 398
Muscular Dystrophy Canada, 251
Mutations, 50, 234–236, 282–283
definition of, 204
effects of, 310
and evolution, 310
induced, 236
rates of, 310
as source of variation, 309
spontaneous, 236
types of, 234–235
Mutualism, 47
Mycelium, 82
Mycobacterium tuberculosis, 454
Mycorrhiza, 84
Mycorrhizae, 84
Mycorrhizal fungi, 560
Myocardial infarction, 502
Myogenic muscle, 498

N

National DNA Data Bank, 243
National Institutes of Health, 202
Natural populations, 286–287
Natural rubber, 557
Natural selection, 304, 326–335
Nature, 240, 356, 357, 660
Nausea, 421
Negrette, Americo, 202

Nematocyst, 99
Nematodes, 102
Neurodegenerative diseases, 238
Neurofibromatosis, 206
Neutral mutation, 282, 310
Newborn screening program, 207
Nitrogen atoms, 308
Nitrogenous base, 229, 241
Nitroglycerin, 501
Non-coding DNA, 240
Non-disjunction, 234
  definition of, 161–163
Non-disjunction disorders, 162–163
Non-invasive tests, 504–507
Notation of alleles, 194
Notochord, 98
Nuclein, 228
Nucleoid, 48
Nucleotide, 229
Numerical prefixes, 669
Nutrients, 396, 609
Nutrition labels, 492
Nutrition Laboratory of the Carnegie Institute of Washington, 398
Nymphaeales, 94, 544

O

Obesity, 404
Obligate aerobe, 49
Obligate anaerobe, 49
O blood type, 195–196
Observational studies, 652–653
Observations, 304, 651, 652, 653, 654
Observing meiosis, 171–172
Oils, 402
Omega-3 fatty acids, 402
Ontario healthcare system, 463
On the Origin of Species (Darwin), 21, 302, 304–307
On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle of Life (Darwin), 304
Oogenesis, 157
Open circulatory systems, 479
Order, 17
Organelles, 48
Organic chemical, 49
Organic material, 648
Organisms and safe handling of, 647
Origin of species, 324
Ornithine transcarboxylase deficiency (OTCD), 249
Ornithischia, 349
Osmosis, 416, 565
Ova, 152
Ovaries, 152
Overeating, 404
Ovule, 92
Ovum, 152
Oxidizing materials, 644
Oxygen, 438, 447, 609
  maintenance levels of, 450–451
Oxygen consumption, 443
Oxygen diffusion, 448
Oxygen transport, 448
Oxygen usage, 444
Oysters, 102

P

Pacini, Filippo, 425
Paleontologists, 291, 292
Paleontology, 291, 292, 313
Palisade mesophyll, 548
Pancreas, 508
  role in digestion, 414–416
Pancreatic duct, 414
Pandemic, 54
Paramecia, 64
Paramecium, 63
Parasitic diseases, 102
Parasitic fungi, 81
Parkinson's disease, 238
Partial pressures, 447
Passive processes, 671
Passive transport, 416, 565
Patagonia, 294
Patau syndrome, 162
Patent attorney, 148
Paternal inheritance, 168
Pathogens, 46, 102
Pathways in biology, 668
Patient medical case history file, 265
Patterns of change, 289–292
Patterns of evolution, 341–345
Pea plant, 185, 210
Peat mosses, 89
Pedigree charts, 197
  tutorial, 198–199
Pedigrees, 197–203
Peer review, 660
Penicillin, 51, 80
Pepsin, 410, 415
Peptidoglycan, 49
Perfluorocarbon emulsions (PFCEs), 486
Perforation plates, 555
Performing and recording, 650
Pericardium, 496
Pericarp, 600
Periodic table of elements, 672–673
Peristalsis, 409
Pesticides, 102
Pet clones, 150
Petiole, 547
PET (positron emission tomography) scan, 203, 505
P generation, 185
Phages, 55
Pharmacist, 561
Pharynx, 408
Phenotype, 187–188
Phenotypic ratios, 211
Phenylketonuria (PKU), 205–206
Phenylthiocarbamide (PTC) tasting, 183
Phlebotomist, 195
Phloem cells, 554, 555, 564
Phloem sap, 568
Phloem to sink
  as sugar transport stage, 570
Phosphate group, 229, 438
Phosphorus, 403, 609
Phosphorylation, 438
Photoperiodism, 608–609
Photopigments, 547
Photoreceptor, 608
Photosynthesis, 87, 396, 542, 547
Photosynthetic
  bacteria, 47, 48
  cyanobacteria, 83
  microorganisms, 11
  prokaryotes, 61
Phototropisms, 613
Phylogenetic classification, 24
Phylogenetic tree, 28, 62
  of animal kingdom, 98
  definition of, 21
  of deuterostomes, 104
  of plant kingdom, 87
  and relationship among three domains, 47
Phylogeny, 350
  definition of, 21
  of fungi, 80–81
  and modern taxonomy, 21–25
  of plants, 86–87
Phylum, 17
Physical digestion in the mouth, 408
Phyte, 86
Phytoplankton, 64
Pili, 48
Pilus, 48
Pioneer species, 588
Pitcher plant, 542
PKU (phenylketonuria), 205–206
Plan for action
  biodiesel, 604
  diabetes management, 509
  extinction is forever, 347
  genetic technology, 253
  genetic testing, 209
  healthcare system, 464
  trees in urban areas, 574
Planning for your future, 668
Plant-based plastic substitute, 541
Plant biology, 630
Plant breeder, 286
Plant cloning, 146

Plant conservation initiatives, 93
Plant growth
and control of, 613–618
and development, 605–612
and environmental factors, 608–612
Plant growth regulators, 613–617
and tropisms, 613
use in plant tissue cultures, 617–618
Plant kingdom, phylogenetic tree of, 87
Plant life cycles, 88
Plant macronutrients, 609
Plant pathogens, 58
Plant physiologist, 608
Plant products, 630
Plants, 27, 86–95, 246
basic needs of, 542–543
characteristics of, 87, 542–545
classification of, 86–87
flowering, 93–94
and human society, 630
importance of, 86, 540
overview of transport in, 564
phylogeny of, 86–87
and response to changes in the environment, 586
and safe handling, 647
as sources of protein, 401
and types of growth, 605–606
"plant stress hormone," 616
Plant tissue cultures, 617–618
Plaque, 501
Plasma, 448, 449, 482
Plasmids, 49, 245
Plasmodium, 60, 64, 66
Platelets, 483
Plate tectonics, 312
Platypus, 311
Pleural membranes, 443
Pneumonia, 455
Pneumothorax, 443
Point-and-line graphs, 666–667
Point mutations, 234, 237
Poison dart frogs, 277
Poisonous symbol, 643
Pollen, 92, 184
Pollen tube, 597
Pollination, 597, 599–600
Pollinators, 600
Polygamy, 366
Polyploids, 139
Polyploidy, 339
Polysaccharides, 400
Population sizes, 302
Positron emission tomography (PET) scan, 203, 505
Postzygotic mechanisms, 336–337
Pre-capillary sphincter muscles, 489
Precision, 664–665
Predator-prey relationship, 314
Prediction, 306, 653
Prefixes, 669
Prenatal testing, 163
Preparation, 655
Preponderance of evidence, 296–303
Prezygotic mechanisms, 336–337
Primary growth, 605, 606
Primary succession, 588–590
Primates, 358
"primitive" species, 325
Principle of inheritance of acquired characteristics (Lamarck), 288
Principle of relatedness, 19
Principle of use and disuse (Lamarck), 288
Principles of Geology (Lyell), 294
Prions, 58
Probability, 188, 213, 665–666
Procedures, 120, 264, 524–525, 651, 652, 653, 654
Producers, 14, 47, 66
Product law, 213
Prokaryotes, 46–53
definition of, 26
and environmental change, 52
importance of, 46–47
Prokaryotic ancestor, 61
Prophase, 144
Prophase I, 154
Prophase II, 155
Prop roots, 561
Prosecretin, 415
Prosimians, 358
Prostate Cancer Research Foundation of Canada, 209
Protection, 11, 547
Protein enzymes, 415
Proteins, 401, 410
and animal products, 401
and plant sources, 401
Proteobacteria (purple bacteria), 48
Protista, 27
Protistology, 66
Protists, 26, 60–69
characteristics of, 63
classification of, 62
interactions in ecosystems, 64
life cycles of, 64–66
Protostome invertebrates, 100–102
Protostomes, 98
and benefit to humans, 102
and competition with humans, 102
Pseudogenes, 310–311
Psychotropic drugs, 551
Pterophytes, 90–91
Puijila darwini, 311
Pulmonary circuit, 481
Pulmonologist, 204
Pulse points, 488
Punctuated equilibrium, 352–353
Punnett square, 188, 204
"purists," 24
Purkinje fibres, 499
Purpose, 120, 264, 524, 651, 652–653
Pus, 483
P wave, 500
Pyloric sphincter, 414

Q

QRS complex, 500
Queen Victoria, 200

R

Radial symmetry, 97
Radiation, 234
Radioactive carbon 14, 308
Radioisotopes, 308, 670
Radiometric dating, 308
Rat snakes, 9
Reactive materials, 644
Recessive allele, 187
Recessive factor, 186
Recombinant DNA, 245
Rectum, 418
Red blood cells, 448
Reference, 669–673
Registered healthcare lobbyist, 252
Regulation of heart rhythm, 498–499
Remote island species, 297
Reporting on the investigation, 651, 652, 653
Reports, 651, 652, 653, 665
Reproduction, 11, 152–166
asexual reproduction, 139
defined, 139–140
sexual reproduction, 140
Reproduction technology careers, 165
Reproductive isolating mechanisms, 336–337
Reproductive technology
implications of, 165
non-human applications of, 165–166
Research, 378–379, 631, 661
Research articles, 660
Research skills, 661
Residual volume, 443
Respiratory infections, 454–456
Respiratory processes, 440–446
Respiratory structures, 440–446
in fish, 445–446
in mammals, 440–444
Respiratory system, 436–468
disorders of, 452–456
need for a, 438–439
Respiratory therapist, 456
Restriction enzymes, 245
Rhesus factor, 485
Rhizomes, 91, 592
Ribonucleic acid (RNA), 54, 55

Ribosomes, 48
Risk-benefit analysis model, 661
RNA (ribonucleic acid), 54, 55
Rocky Mountains, 338
Root cap, 559
Root cortex, 559
Root hair, 558
Root pressure, 566
Roots, 543, 558–563
  function of, 558
  human uses of, 561
  structure of, 559
Roots and Shoots, 106
Root specialization, 560–561
Root systems, 558
Roslin Institute (Scotland), 147
Rosy periwinkle, 550
Rotifers, 100
Rounding, 664
Royal genes, 200
Rybczynski, Natalia, 311

S

Safety
  and chemicals, 647
  and electricity, 647
  eye, ear, and face, 645
  and fire, 646
  and glassware, 645
  and handling animals, 647
  and handling organisms, 647
  and handling plants, 647
  and heat, 646
  in the laboratory, 645
  and use of sharp instruments, 646
Safety conventions, 643–644
Safety skills, 643–648
Safety symbols, 643–644
Sahelanthropus, 359
Salivary glands, 408
Salmonella, 422, 647
Salt, 492
Salter, Steven, 571
SA node, 500
Saturated triglycerides, 402
Saurischia, 349
Scala naturae, 17
Scale ratio, 656
Scavengers, 14
Science, 240
Science, technology, society and the environment (STSE). *see* STSE
Science of breeding, 285
"Science of Systematics," 15
Scientific detective work, 424
Scientific inquiry, 649–654
Scientific journals, 660
Scientific methods, use of, 424
Scientific model, 230–231
Scientific notation, 663
Scientific publications, 660
Scientific theory, 280
Scion, 594
Scolex, 102
Seasons, 608
Seaweed, 64
Secondary growth, 605, 607
Secondary succession, 590, 595
Secrete, 408
Secretin, 415
Secretion, 408
Seed banks, 601
Seed function, 595–596
Seed plants, 91–94
  and asexual reproduction, 592–594
  and sexual reproduction, 595–601
Seeds, 92
  and gravity, 587
  human use of, 601
Seed structure, 595–596
Selective breeding, 283–286
Selective pressure, 329
Self pollination, 600
Semilunar valves, 496
Senescence, 616
Septum, 82, 480
Serum, 482
Sex chromosomes, 158–160, 200–201
Sex determination, 158–160
Sex linkage, 200–201
Sex-linked, 200
Sexual dimorphism, 366–367
Sexual gametes, 152
Sexual reproduction, 152–159
  in angiosperms, 597–599
  costs and benefits of, 596
  and cytoplasmic inheritance, 167–168
  definition of, 140
  in gymnosperms, 596
  modes of, 152
  and seed plants, 595–601
Sexual selection, 328
Sharp instruments
  and safe usage, 646
Shoots, 543
Shorthorn cattle, 195
Shubin, Neil, 356–357
Sickle-cell anemia, 235, 282, 326
Sieve cells, 555
Sieve plates, 555
Sieve tube elements, 555
Significant digits, 663–664
Simple diffusion, 416
Simple invertebrates, 99
SINE (short interspersed element), 367
Single-celled algae, 228
Single-celled life, 348
Single circuit, 480
Sink plant cells, 568
Sinoatrial (SA) node, 499
SI prefixes, 669
Sister chromatid, 143
SI unit (International System of Units), 398, 669
Size, estimation of, 658
Skills of scientific inquiry, 649–650
  analyzing and interpreting, 650
  communicating, 650
  initiating and planning, 649
  performing and recording, 650
Skin melanoma, 236
Slide preparation, 658
Slime moulds, 63
Slug, 102
Small intestine
  absorption in, 416–417
  segments of the, 413
  structure of the, 412–413
Smallpox, 57
Smoking, effect on gas exchange, 457–458
Snails, 100
Snapdragons, 194
Snow, John, 424
Snowshoe hares, 282
Sodium, 403, 492
Soil, 611–612
"soil water," 564
Solar water pump, 571
Somatic cell mutation, 236
Source plant cells, 568
Source to phloem, 569
Speciation, 336–340
  and human influence, 340
  modes of, 336–339
Species, 17
  definition of, 8, 336
  and diversity, 10
  extinction of, 12
  interactions with, 11
  naming of, 17
  on remote islands, 297
  variety of, 15
Spermatogenesis, 157
Sperm cells, 152
Sphagnum, 89
Sphincters, 409
Sphygmomanometer, 477, 491
  use of, 659
Spider silk, 247
Spiral, 49
Spirilli, 49
Spirillum, 49
Spirometer, 444
Spleen, 493
Sponges, 99, 478
Spongy mesophyll, 548

Spontaneous mutation, 236
Sporangia, 89
Sporangium, 89
Spore, 65
Sporophyte, 65, 88
Squash, 601, 610
Stabilizing selection, 327
Stages of meiosis, 153–156
Staining techniques, 658–659
Stamens, 598
Staphylo, 49
Staphylococci, 49
Staphylococcus aureus (MSRA), 282
Starch in roots, 562
Statistics Canada, 540, 552, 573
Stems, 543, 552–557
  functions of, 552
  human use of, 556
Stem specializations, 555–556
Stem structure, 552
Stent, 502
Steroids, 402
Stethoscope, 477
  use of, 659
Steward, Frederick, 146
Stigma, 598
Stock, 594
Stoma, 89, 548
Stomach and chemical digestion, 410
Stomach ulcers, 410
Stomata, 89, 548
Storage, 547
Strangler fig roots, 560
Streptococci, 49
Stroock, Abraham, 572
Structural diversity, 10
Structure
  of the heart, 495
  of the large intestine, 418–419
  of leaves, 547
  of roots, 559
Study design, 651–652
Style, 598
Success in numbers, 45
Succession, 588–591
Sudan IV indicator, 659
Sudbury, 591
Sugar transport, 568
Sun, 396
Sundews, 87
Sunlight, 608
  and seasonal changes, 608
Superorders, 17
Surface area, 412
Survival of the fittest, 305
Sutherland, Katie, 460
Swallowing reflex, 408
Swimmer's itch, 102
Symbiotic organisms, 61
Symbiotic relationships, 344
  in ecosystems, 83–84
Sympatric speciation, 339
Synapomorphy, 350, 351
Synapsis
Systema Naturae (Linnaeus), 17
Systemic circuit, 481
Systole, 497
Systolic pressure, 491

T

Tapeworms, 100, 102
Taproots, 560
Taproot systems, 558
Target cells, 249
Taxon, 17
Taxonomists, 25
Taxonomy, 15–16, 21
Taxonomy today, 24–25
Tay-Sachs disease, 206
Tea, 546
Teeth, 408
Telophase, 145
Telophase I, 154
Telophase II, 155
Temperature, 610
Terrestrial ecosystems, 78
Terrestrial organisms, 78
Testable question, 650, 653
Test cross, 190–191
Testes, 152
Test hypotheses, 281
Tetrad, 154
Texas Longhorn, 285
Textile dye, 561
The Biomimicry Guild and Institute, 571
"the guinea pig doctor," 410–411
Theory of evolution, 304–307
Theory of evolution, modern, 308–313
Theory of gradualism, 353
Theory of gravity, 280
Theory of natural selection, 304–307
Theory of punctuated equilibrium, 353
Thermal energy, 396
"the silent killer," 492
Thigmotropism, 614
Thoracic surgeon, 461
Three Sisters, 93
Thymine, 229, 231
Thymus, 494
Tibetans, 329
Tidal volume, 443
Tiktaalik roseae, 356–357
Title, 653
Toluidine blue, 659
Tomato plants, 284
Total lung capacity, 443
Toxic substances, 644, 648
Trachea, 441
Tracheid, 555
Trachops cirrhosus, 24
Traditional classification, 24
Traditional taxonomic ranks of classification, 17
Trait, 184
Transduction, 56
Transformation, 50
Transitional forms, 354
Translocation, as sugar transport stage, 569
"transmutation of species," 296
Transpiration, 567
Transport
  to the leaves, 567
  of nutrients, 565
  into the roots, 565
  into the stems, 566
  of sugars, 568–570
  in vascular plants, 564–570
  of water, 565–567
  in xylem tissue, 566
Transportation
  of carbon dioxide, 448–449
  of oxygen, 448
  as species interaction, 11
Transposition, 237
Transposons, 237
Tree bark, 542
Tree of Life, 21, 348–350
Triceratops, 291
Trichocysts, 63
Triglycerides, 402
Trisomy, 161
Tropical rainforests, 277
Tropisms, 613
"true bacteria," 26
True-breeding organism, 184
Trypsin, 415
Tsui, Lap-chee, 204, 455
Tuberculosis (TB), 454
Tuberous roots, 560
Tubers, 592
Tumour suppressors, 205
Turgor, 567
Turner syndrome, 162
T wave, 500
Two-chambered heart, 480
Two-circuit circulatory system, 481
Type 1 diabetes, 508
Type 2 diabetes, 508
Type A blood, 195–196, 485
Type B blood, 195–196, 485
Type O blood, 195–196, 485
Types of growth, 605
Types of root systems, 558

U

Ulcers, 410–411
Ultrasound, 163

Uncertainty in measurements, 663–665
Uniformitarianism, 291–292
Université Laval, 251
University Health Network, 462
University of Calgary, 148
University of Chicago, 356
University of Guelph, 243
University of Pennsylvania, 250
University of Wisconsin, 329
University programs, 668
Unsaturated triglycerides, 402
Urbanization, 573
Urban planner, 573

V

Vaccinations, 57
Vacuoles, 63
Valerian, 561
Variability, 137
Variables, 650, 651, 654
Varicose veins, 491
Variety, value of, 136
Vascular bundle, 553
Vascular cambium, 553
Vascular cylinder, 559
Vascular plants, 543–545
  transport in, 564–570
Vascular tissues, 543, 554–555
Vasoconstriction, 488
Vasodilation, 488
Vectors, 102, 249
Veins, 490–491
Velcro, 571
Venation, 548
Ventilation, 438–439
  definition of, 439
  mechanism of, 442–443
Ventricle, 480
Venules, 490–491
Vertebrate diversity, 106
Vertebrates, 98, 105
Vessel element, 555
Vestigial features, 300–301
Vibrio cholerae, 425
Villi, 413
Villus, 413
Vincristine, 550
Viral diseases, 54
  and the World Health Organization (WHO), 57
Viral transmission, 57
Viroids, 58
Viruses, 54–58
Vital capacity, 443
Vitamins, 403
VO_2, 444
VO_2max, 444
Vomiting, 421–422

W

Walkerton (Ontario), 422
Walking palm, 605
Wallace, Alfred Russell, 304
Waller, Augustus, 499
Warren, Robin, 410–411
Waste disposal, 648
Water, 402
Water lilies, 94, 572
Watson, James, 230
Wavelengths, 608
Web of life, 106
Weinberg, Wilhelm, 333
Wet-mount slide, 658
Wexler, Nancy, 202
White blood cells, 483
WHMIS (Workplace Hazardous Materials Information System), 643–644
WHO. *see* World Health Organization
Whole body scans, 391
Wildlife corridors, 340
Wild sea cabbage, 284
Wilkins, Maurice, 230
Willow bark and modern medicine, 557
Wilmut, Ian, 147
Wilson, Edward O., 13
Windpipe, 441
Woese, Carl, 28
Woody, 552
Woody stems, 553–554
Workplace Hazardous Materials Information System (WHMIS), 643–644
World Health Organization (WHO), 57, 283, 454
Worms, 100

X

X chromosomes, 200–201
X-linked, 200
X-ray crystallography, 230
Xylem, 564
Xylem cell types, 555
Xylem sap, 567
Xylem tissue, 553–554

Y

Y chromosomes, 200–201
Yeast, 82, 83
Y-linked, 201

Z

Zone of maturation, 606
Zucchini, 601
Zygote, 64, 152–153

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